Low Temperature Physics Division
Fachverband Tiefe Temperaturen (TT)

Elke Scheer
Universität Konstanz
Fachbereich Physik
78457 Konstanz
elke.scheer@uni-konstanz.de

Overview of Invited Talks and Sessions

(Lecture halls H3, H10, H22, and H23; Poster P1)

Plenary Talk

PLV I	Mon	8:30– 9:15	H1	**Intrinsic Josephson junctions in $Bi_2Sr_2CaCu_2O_8$: Generation of Terahertz radiation and beyond** — •Reinhold Kleiner

Invited Talks

TT 1.1	Mon	9:30–10:00	H10	**Stability of Floquet Majorana box qubits** — •Anne Matthies
TT 5.1	Mon	15:00–15:30	H10	**Dynamics of visons and thermal Hall effect in perturbed Kitaev models** — •Aprem Joy
TT 10.1	Tue	9:30–10:00	H3	**Two-fold symmetric superconductivity in few-layer $NbSe_2$** — •Vlad Pribiag
TT 10.2	Tue	10:00–10:30	H3	**Spin-orbit coupling and triplet pairing in mesoscopic superconductors** — •marco aprili
TT 10.3	Tue	10:30–11:00	H3	**Supercurrent diode effect in few-layer $NbSe_2$** — •Nicola Paradiso
TT 10.4	Tue	11:15–11:45	H3	**Superconducting devices in magic-angle twisted bilayer graphene** — •Folkert de Vries
TT 10.5	Tue	11:45–12:15	H3	**Minigap and Andreev bound states in ballistic graphene** — •Luca Banszerus
TT 16.1	Wed	9:30–10:00	H10	**Multimethod, multimessenger approaches to models of strong correlations** — •Thomas Schäfer
TT 22.1	Wed	15:00–15:30	H10	**Evidence for orbital loop current magnetism in Sr_2RuO_4** — •A. Di Bernardo
TT 22.8	Wed	17:15–17:45	H10	**Role of the film geometry in the electronic reconstruction of infinite-layer nickelates on $SrTiO_3$(001)** — •Benjamin Geisler
TT 25.1	Thu	9:30–10:00	H3	**Topology: Open and with diverse backgrounds** — •Tobias Meng
TT 28.5	Thu	10:30–11:00	H23	**Towards an *ab-initio* theory of Anderson localization for correlated electrons** — •Liviu Chioncel
TT 32.1	Thu	15:00–15:30	H10	**Supercurrents in HgTe-based topological nanowires** — •Dieter Weiss
TT 32.2	Thu	15:30–16:00	H10	**Majorana bound states and non-reciprocal transport in topological insulator nanowire devices** — •Henry Legg
TT 32.3	Thu	16:00–16:30	H10	**Integration of topological insulator Josephson junctions in superconducting qubit circuits** — •Tobias W. Schmitt
TT 32.4	Thu	16:45–17:15	H10	**Universal fluctuations of the induced superconducting gap in an elemental nanowire** — •Matthieu Delbecq
TT 32.5	Thu	17:15–17:45	H10	**Exploring the full potential of edge channel transport in HgTe based two-dimensional topological insulators** — •Saquib Shamim
TT 36.1	Fri	9:30–10:00	H10	**Coherent control of lattice and electronic states** — •Steven Johnson
TT 36.2	Fri	10:00–10:30	H10	**New opportunities for light-matter control of quantum materials** — •Michael Sentef
TT 36.3	Fri	10:30–11:00	H10	**Coherent electronic control of an insulator-to-metal transition** — •Claudio Giannetti
TT 36.4	Fri	11:15–11:45	H10	**Nanoscale transient magnetization dynamics: A comprehensive EUV TG study** — •Laura Foglia
TT 36.5	Fri	11:45–12:15	H10	**Ultrafast magnetism of antiferromagnets** — •Alexey Kimel

Invited Talks of the joint Symposium Frontiers of Orbital Physics: Statics, Dynamics, and Transport of Orbital Angular Momentum (SYOP)

See SYOP for the full program of the symposium.

SYOP 1.1	Mon	9:30–10:00	H1	**Orbital degeneracy in transition metal compounds: Jahn-Teller effect, spin-orbit coupling and quantum effects** — •Daniel Khomskii
SYOP 1.2	Mon	10:00–10:30	H1	**Orbital magnetism out of equilibrium: driving orbital motion with fluctuations, fields and currents** — •Yuriy Mokrousov
SYOP 1.3	Mon	10:30–11:00	H1	**Orbitronics: new torques and magnetoresistance effects** — •Mathias Kläui
SYOP 1.4	Mon	11:15–11:45	H1	**Orbital and total angular momenta dichroism of the THz vortex beams at the antiferromagnetic resonances** — •Andrei Sirenko
SYOP 1.5	Mon	11:45–12:15	H1	**Observation of the orbital Hall effect in a light metal Ti** — •Gyung-Min Choi

Invited Talks of the joint Symposium SKM Dissertation Prize 2022 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	10:15–10:45	H2	**Charge localisation in halide perovskites from bulk to nano for efficient optoelectronic applications** — •Sascha Feldmann
SYSD 1.2	Mon	10:45–11:15	H2	**Nonequilibrium Transport and Dynamics in Conventional and Topological Superconducting Junctions** — •Raffael L. Klees
SYSD 1.3	Mon	11:15–11:45	H2	**Probing magnetostatic and magnetotransport properties of the antiferromagnetic iron oxide hematite** — •Andrew Ross
SYSD 1.4	Mon	11:45–12:15	H2	**Quantum dot optomechanics with surface acoustic waves** — •Matthias Weiss

Invited Talks of the joint Symposium United Kingdom as Guest of Honor (SYUK)

See SYUK for the full program of the symposium.

SYUK 1.1	Wed	9:30–10:00	H2	**Structure and Dynamics of Interfacial Water** — •Angelos Michaelides
SYUK 1.2	Wed	10:00–10:30	H2	**A molecular view of the water interface** — •Mischa Bonn
SYUK 1.3	Wed	10:30–11:00	H2	**Motile cilia waves: creating and responding to flow** — •Pietro Cicuta
SYUK 1.4	Wed	11:00–11:30	H2	**Cilia and flagella: Building blocks of life and a physicist's playground** — •Oliver Bäumchen
SYUK 1.5	Wed	11:45–12:15	H2	**Computational modelling of the physics of rare earth - transition metal permanent magnets from $SmCo_5$ to $Nd_2Fe_{14}B$** — •Julie Staunton
SYUK 2.1	Wed	15:00–15:30	H2	**Hysteresis Design of Magnetic Materials for Efficient Energy Conversion** — •Oliver Gutfleisch
SYUK 2.2	Wed	15:30–16:00	H2	**Non-equilibrium dynamics of many-body quantum systems versus quantum technologies** — •Irene D'Amico
SYUK 2.3	Wed	16:00–16:30	H2	**Quantum computing with trapped ions** — •Ferdinand Schmidt-Kaler
SYUK 2.4	Wed	16:45–17:15	H2	**Breaking the millikelvin barrier in cooling nanoelectronic devices** — •Richard Haley
SYUK 2.5	Wed	17:15–17:45	H2	**Superconducting Quantum Interference Devices for applications at mK temperatures** — •Sebastian Kempf

Invited Talks of the joint Symposium Complexity and Topology in Quantum Matter (SYQM)

See SYQM for the full program of the symposium.

SYQM 1.1	Fri	9:30–10:00	H1	**The role of crystalline symmetries in topological materials: the topological materials database** — •Maia Vergniory
SYQM 1.2	Fri	10:00–10:30	H1	**Microwave Bulk and Edge Transport in HgTe-Based 2D Topological Insulators** — •Erwann Bocquillon
SYQM 1.3	Fri	10:30–11:00	H1	**Spectral Sensitivity of Non-Hermitian Topological Systems** — •Jan Carl Budich
SYQM 1.4	Fri	11:15–11:45	H1	**Topological photonics and topological lasers with coupled vertical resonators** — •Sebastian Klembt
SYQM 1.5	Fri	11:45–12:15	H1	**Spectroscopic Studies of the Topological Magnon Band Structure in a Skyrmion Lattice** — •Markus Garst

Sessions

TT 1.1–1.13	Mon	9:30–13:15	H10	**Topology: Majorana Physics**
TT 2.1–2.14	Mon	9:30–13:15	H22	**Nanotubes, Nanoribbons and Graphene**
TT 3.1–3.13	Mon	9:30–13:00	H23	**Superconductivity: Properties and Electronic Structure**
TT 4.1–4.10	Mon	10:00–12:45	H20	**Many-Body Quantum Dynamics 1 (joint session DY/TT)**
TT 5.1–5.7	Mon	15:00–17:00	H10	**Frustrated Magnets – Spin Liquids**
TT 6.1–6.12	Mon	15:00–18:15	H22	**Kondo Physics, f-Electron Systems and Heavy Fermions**
TT 7.1–7.11	Mon	15:00–18:00	H23	**Fluctuations, Noise, Magnetotransport, and Related Topics**
TT 8.1–8.7	Mon	17:15–19:00	H10	**Frustrated Magnets – Strong Spin-Orbit Coupling**
TT 9.1–9.5	Mon	18:00–19:15	H23	**Cold Atomic Gases and Superfluids**
TT 10.1–10.9	Tue	9:30–13:15	H3	**Focus Session: Superconductivity in 2d-Materials and their Heterostructures**
TT 11.1–11.11	Tue	9:30–12:30	H10	**Topology: Quantum Hall Systems**
TT 12.1–12.13	Tue	9:30–13:00	H22	**Correlated Electrons: Materials**
TT 13.1–13.6	Tue	9:30–11:00	H23	**Quantum Dots, Quantum Wires, Point Contacts**
TT 14.1–14.6	Tue	11:30–13:00	H20	**Many-Body Quantum Dynamics 2 (joint session DY/TT)**
TT 15.1–15.6	Tue	11:15–12:45	H23	**Nano- and Optomechanics**
TT 16.1–16.13	Wed	9:30–13:15	H10	**Correlated Electrons: Method Development**
TT 17.1–17.9	Wed	9:30–12:00	H22	**Cryogenic Detectors and Cryotechnique**
TT 18.1–18.9	Wed	9:30–11:45	H23	**Topological Insulators**
TT 19.1–19.5	Wed	11:45–13:00	H23	**Topological Superconductors**
TT 20.1–20.11	Wed	15:00–18:00	P1	**Topology: Poster Session**
TT 21.1–21.38	Wed	15:00–18:00	P1	**Correlated Electrons: Poster Session**
TT 22.1–22.14	Wed	15:00–19:15	H10	**Unconventional Superconductors**
TT 23.1–23.13	Wed	15:00–18:30	H22	**Frustrated Magnets - General**
TT 24.1–24.15	Wed	15:00–19:00	H23	**Quantum-Critical Phenomena**
TT 25.1–25.13	Thu	9:30–13:15	H3	**Topological Semimetals**
TT 26.1–26.13	Thu	9:30–13:00	H10	**Superconductivity: Tunnelling and Josephson Junctions**
TT 27.1–27.11	Thu	9:30–12:30	H22	**Quantum Coherence and Quantum Information Systems (joint session TT/DY)**
TT 28.1–28.12	Thu	9:30–13:00	H23	**Correlated Electrons: Theory 1**
TT 29.1–29.18	Thu	15:00–18:00	P1	**Transport: Poster Session**
TT 30.1–30.24	Thu	15:00–18:00	P1	**Superconductivity: Poster Session**
TT 31.1–31.26	Thu	15:00–18:00	P1	**Superconducting Electronics and Cryogenics: Poster Session**
TT 32.1–32.8	Thu	15:00–18:30	H10	**Focus Session: Topological Devices (joint session TT/KFM)**
TT 33.1–33.12	Thu	15:00–18:15	H22	**Nonequilibrium Quantum Many-Body Systems (joint session TT/DY)**
TT 34.1–34.14	Thu	15:00–18:45	H23	**Correlated Electrons: Theory 2**
TT 35	Thu	19:00–20:00	H22	**Members' Assembly**
TT 36.1–36.5	Fri	9:30–12:15	H10	**Focus Session: Ultrafast Spin, Lattice and Charge Dynamics of Solids**
TT 37.1–37.14	Fri	9:30–13:15	H22	**Superconducting Electronics: SQUIDs, Qubits, Circuit QED**
TT 38.1–38.6	Fri	9:30–11:00	H23	**Superconductivity: Theory**
TT 39.1–39.8	Fri	11:15–13:15	H23	**Correlated Electrons: Charge Order**

Members' Assembly of the Low Temperature Physics Division

Thursday 19:00–20:00 H22

- Bericht
- Verschiedenes

I gratefully acknowledge the invaluable support of R. Hott in composing the program. Many thanks to the former divisional spokespersons C. Enss and U. Eckern for their careful cross reading and advice.

TT 1: Topology: Majorana Physics

Time: Monday 9:30–13:15 Location: H10

Invited Talk TT 1.1 Mon 9:30 H10

Stability of Floquet Majorana box qubits — •Anne Matthies — Institute for Theoretical Physics, University of Cologne, Germany

A topological superconductor in one dimension can host Majorana zero modes at its edge. By driving the system periodically, so-called π modes (also named Floquet-Majoranas) can arise. These are topologically protected modes with the quasi-energy π/T, where T is the period of the drive. We consider the role of π modes in the presence of long-range Coulomb interactions and therefore study a Cooper pair box made of two Josephson coupled superconducting topological quantum wires. Time-dependent gate voltages periodically drive the system and can induce π modes. The presence of four Majoranas and four π Majoranas in our setup allows us to define three topological qubits in a fixed fermion parity sector within one single box. We investigate how to obtain and control the π modes and study their stability in the presence of interactions. The stability of the Floquet-Majorana box qubit depends crucially on the initialization of the Floquet state. If the system is prepared by adiabatically increasing the amplitude of the oscillating gate voltage, the topological Floquet phase is always inherently unstable. The instability arises due to resonant quasi-particle creation mediated by interactions. However, a stable Floquet phase can be reached by using a two-step protocol. First, the amplitude of the oscillating gate voltage is adiabatically increased, while the frequency of the oscillation is small. Then, the oscillation frequency is increased slowly. With this frequency-sweep protocol, we can achieve a stable Floquet device despite interactions.

[1] PRL 128, 127702

TT 1.2 Mon 10:00 H10

Quantized phase-coherent heat transport of counterpropagating Majorana modes — Alexander G. Bauer[1], Benedikt Scharf[2], Laurens W. Molenkamp[3], Ewelina M. Hankiewicz[2], and •Björn Sothmann[1] — [1]Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany — [2]Institute of Theoretical Physics and Astrophysics and Würzburg-Dresden Cluster of Excellence ct.qmat, University of Würzburg, Am Hubland, 97074 Würzburg, Germany — [3]Experimentelle Physik III, Physikalisches Institut, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

We demonstrate that phase-coherent heat transport constitutes a powerful tool to probe Majorana physics in topological Josephson junctions. We predict that the thermal conductance transverse to the direction of the superconducting phase bias is universally quantized by half the thermal conductance quantum at phase difference $\phi = \pi$. This is a direct consequence of the parity-protected counterpropagating Majorana modes which are hosted at the superconducting interfaces. Away from $\phi = \pi$, we find a strong suppression of the thermal conductance due to the opening of a gap in the Andreev spectrum. This behavior is very robust with respect to the presence of magnetic fields. It is in direct contrast to the thermal conductance of a trivial Josephson junction which is suppressed at any phase difference ϕ.

[1] A. G. Bauer, B. Scharf, L. W. Molenkamp, E. M. Hankiewicz, B. Sothmann, Phys. Rev. B **104**, L201410 (2021)

TT 1.3 Mon 10:15 H10

Cookbook for perfect topological Majorana fermions — •Prathyush P. Poduval[1,2], Thomas L. Schmidt[1], and Andreas Haller[1] — [1]University of Luxembourg, Luxembourg, Luxembourg — [2]Indian Institute of Science, Bangalore, India

It has been demonstrated that Majorana corner modes of higher order topological insulators (HOTI) can be rotated by magnetic and superconducting pairing fields which pump the corner modes through the edges, and effectively realise a two-fold particle exchange [1]. These results are based on exact diagonalization of quadratic Hamiltonians that predict extended corner Majorana modes. Here, we show analytically that the topological phase of the 2D Majorana HOTI model can be adiabatically deformed to a scenario we dub "sweet spot limit", with perfectly localized Majorana corner modes. The existence of sweet spot limits are important for obtaining analytical solutions and also for possible experimental realizations with constraints on the total number of lattice nodes. Our findings are based on a systematic corner mode construction, which we apply to known lattice models in one and two spatial dimensions. The key idea is to obtain the typical lattice dimerization picture of the Hamiltonian matrix elements in a simultaneous eigenbasis of Majorana fermions and the symmetry operator which protects the corner modes. Based on our findings, we propose a novel 3D model featuring perfectly localized Majorana corner modes which avoids the dimensional obstruction encountered in 2D and may pave the way towards braiding.

[1] Phys. Rev. Res. 2, 032068

TT 1.4 Mon 10:30 H10

Edge $\mathbb{Z}_3$ parafermions in fermionic lattices. — •Raphael L R C Teixeira[1,2] and Luis G G V Dias da Silva[1] — [1]Instituto de Fisica - Universidade de Sao Paulo, Sao Paulo Brazil — [2]Department of Physics and Materials Science Université du Luxembourg, Luxembourg, Luxembourg

Parafermions modes are non-Abelian anyons which were introduced as $\mathbb{Z}_N$ generalizations of $\mathbb{Z}_2$ Majorana states. In particular, $\mathbb{Z}_3$ parafermions can be used to produce Fibonacci anyons, laying a path towards universal topological quantum computation. Due to their fractional nature, much of theoretical work on $\mathbb{Z}_3$ parafermions has relied on bosonization methods or parafermionic operators. In this work, we introduce a representation of $\mathbb{Z}_3$ parafermions in terms of purely fermionic models operators in the single-occupancy basis ($t-J$ regime). We establish the equivalency of a family of 1D-lattice fermionic models written in the $t-J$ model basis supporting free $\mathbb{Z}_3$ parafermonic modes at its ends. By using density matrix renormalization group calculations, we are able to characterize the topological phase transition and study the effect of local operators (doping and magnetic fields) on the spatial localization of the parafermionic modes and their stability. Moreover, we discuss the necessary ingredients towards realizing $\mathbb{Z}_3$ parafermions in strongly interacting electronic systems.

TT 1.5 Mon 10:45 H10

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 which are easier to realize and tweak experimentally. We show that localized Majorana states can be found in these systems and investigate possible ranges of parameters. This establishes 2π domain walls as tunable elements for the realization of Majorana devices.

TT 1.6 Mon 11:00 H10

Fraunhofer pattern in the presence of Majorana modes — •Fernando Dominguez[1], Elena G. Novik[2], and Patrik Recher[1,3] — [1]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Institute of Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany — [3]Laboratory for Emerging Nanometrology, 38106 Braunschweig, Germany

We investigate signatures of the presence of Majorana bound states that can arise in the Fraunhofer pattern of Josephson junctions made of Top.Sc/Qu.Spin Hall /Top.Sc. In this setup,the presence of Majorana bound states at the NS interfaces introduces electron-hole reflections with parallel spin, which due to spin-momentum locking, are forced to take place between opposite edges. In contrast to local electron-hole reflections (with opposite spin), the presence of such non-local processes do not accumulate a geometrical phase and therefore, they can change drastically or partially the periodicity of the Fraunhofer pattern. In order to observe such a change in the Fraunhofer pattern, the quantum spin-Hall edges have to be coupled either directly or through the bulk. Here, we propose two different scenarios where this can occur and provide numerical results from a scattering and tight-binding models.

15 min. break

TT 1.7 Mon 11:30 H10

Photonic noise as a probe of Majorana bound states — •Lena Bittermann[1], Fernando Dominguez[1], and Patrik Recher[1,2] — [1]Institut für Mathematische Physik, Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology Braunschweig, D-38106 Braunschweig, Germany

We propose a route to detect Majorana bound states (MBSs) by coupling a topological superconductor to a quantum dot (QD) in a pn-junction. Here, two MBSs are coherently coupled to electrons on the QD, which recombine with holes in situ to photons. Importantly, the polarization of the emitted photons provides direct information on the spin structure [1,2] and nonlocality [2,3] of the MBSs. Here, we focus on the shot noise of the emitted photons which allows to clearly distinguish the cases of well separated MBSs at zero energy from overlapping MBSs. In addition, we show that quasiparticle poisoning changes the shot noise from super-Poissonian to sub-Poissonian. Furthermore, this setup can be extended by coupling a second QD close to the second MBS which gives rise to more resonances in the shot noise leading to additional signatures of the MBSs.

[1] D. Sticlet, C. Bena, P. Simon, PRL 108, 096802 (2012)
[2] E. Prada, R. Aguado, P. San-Jose, PRB 96, 085418 (2017)
[3] A. Schuray, L. Weithofer, P. Recher, PRB 96, 085417 (2017)

TT 1.8 Mon 11:45 H10

Zero energy modes of artificial spin chains from ab initio calculations — •Bendegúz Nyári[1], András Lászlóffy[2], László Szunyogh[1], and Balázs Újfalussy[2] — [1]Department of Theoretical Physics, Budapest University of Technology and Economics, Hungary — [2]Wigner Research Centre for Physics, Institute for Solid State Physics and Optics, Hungary

The conditions under which Majorana zero modes (MZM) appear and their physical properties in realistic materials have been of high interest over the past few years triggered by their possible applications as fault tolerant quantum bits. The MZMs are topological states corresponding to triplet pairing at zero energy emerging in an inner gap inside the superconducting gap. However, experimentally it is very challenging to identify MZMs based solely on the spectral properties. Ab inito calculations are able to reproduce the measured spectral quantities and provide additional information on the nature of the in-gap states reported in corresponding experiments.

In this work we present ab initio calculations in the superconducting state of the in-gap density of states and the singlet and triplet order parameters for Fe chains on Nb(110) surface covered by one monolayer of Au. The Fe chains are also assumed to be in various artificial spin-spiral states. In a wide range of the spin-spiral wavelength we find an inner gap with states at zero-energy and large triplet pairing order parameter. A similar behavior to previous studies based on tight-binding models further supports the conjecture that there are MZMs in this system.

TT 1.9 Mon 12:00 H10

Quantitative theory of of Yu-Shiba-Rusinov states of magnetic adatoms on Nb(110) surface and various overlayers — •Balazs Ujfalussy[1], Andras Laszloffy[1], Bendeguz Nyari[2], Kyungwha Park[3], and Laszlo Szunyogh[2] — [1]Wigner Research Centre for Physics, Budapest, Hungary — [2]Budapest University of Technology, Budapest, Hungary — [3]Department of Physics, Virginia Tech, Blacksburg, Virginia, USA

We present a fully relativistic first-principles-based theoretical approach for the calculation of the spectral properties of Fe, Co, Cr and Mn adatoms on the surface of Nb(110) substrate in the superconducting state, providing a material-specific framework for the investigation of the Yu-Shiba-Rusinov (YSR) states. We study the effect of spin-orbit coupling, the strength of the exchange field and induced moments. Furthermore, we attempt to explain certain features of the STM experiments, and to link some properties to the normal state density of states. In order to study the effect of the substrate, we provide results for the YSR states in the case of impurities on various Nb(110)/overlayer systems as well. We also study the formation of a zero-bias peak for single adatoms and dimers.

TT 1.10 Mon 12:15 H10

Matrix modelling of potential disorder effects on in-gap spectra of a vortex on a proximitized topological insulator surface — •Alexander Ziesen and Fabian Hassler — RWTH Aachen University, Aachen, Germany

We study a heterostructure of a three-dimensional topological insulator and an s-wave superconductor. If a single superconducting flux quantum is trapped on the proximitized surface of the topological insulator, it is theoretically predicted that a Majorana zero mode is hosted in this vortex core. To enable the usage of this non-Abelian anyon for quantum computation, it is essential to maximize the spectral gap between the Majorana zero mode and the first excited in-gap state. For clean systems tuned close to the charge neutrality point of the topological insulator and vortex radii close to the superconducting coherence length, this excitation gap is predicted to be comparable to the superconducting gap. On the other hand, for strongly disordered topological insulators, supersymmetric σ-models of symmetry class BD predict a finite, but experimentally barely resolvable excitation gap. In this work, we build the bridge between both limits with a matrix description of an effective two-dimensional surface model for strong proximization and potential disorder. With it, we quantify the amount of disorder tolerable in the system to allow for experimental resolution.

TT 1.11 Mon 12:30 H10

Steering Majorana braiding via skyrmion-vortex pairs: a scalable platform — Jonas Nothhelfer[1], •Sebastián A. Díaz[1], Stephan Kessler[2], Tobias Meng[3], Matteo Rizzi[4,5], Kjetil M. D. Hals[6], and Karin Everschor-Sitte[1] — [1]University of Duisburg-Essen, Duisburg, Germany — [2]Johannes Gutenberg University of Mainz, Mainz, Germany — [3]Technische Universität Dresden, Dresden, Germany — [4]Forschungszentrum Jülich, Jülich, Germany — [5]University of Cologne, Cologne, Germany — [6]University of Agder, Grimstad, Norway

Majorana zero modes are quasiparticles that hold promise as building blocks for topological quantum computing. However, the litmus test for their detection, the observation of exotic non-abelian statistics revealed by braiding, has so far eluded experimental efforts. Here we take advantage of the fact that skyrmion-vortex pairs in superconductor-ferromagnet heterostructures harboring Majorana zero modes can be easily manipulated in two spatial dimensions. We adiabatically braid the hybrid topological structures and explicitly confirm the non-abelian statistics of the Majorana zero modes numerically using a self-consistent calculation of the superconducting order parameter. Our proposal of controlling skyrmion-vortex pairs provides the necessary leeway toward a scalable topological quantum computing platform.

[1] J. Nothhelfer, S. A. Díaz, S. Kessler, T. Meng, M. Rizzi, K. M. D. Hals, K. Everschor-Sitte, arXiv:2110.13983

TT 1.12 Mon 12:45 H10

Sachdev-Ye-Kitaev circuits for braiding and charging Majorana zero modes — •Jan Behrends[1] and Benjamin Béri[1,2] — [1]TCM Group, Cavendish Laboratory, University of Cambridge, J.J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom — [2]DAMTP, University of Cambridge, Wilberforce Road, Cambridge CB3 0WA, United Kingdom

The Sachdev-Ye-Kitaev (SYK) model is an all-to-all interacting Majorana fermion model for many-body quantum chaos and the holographic correspondence. Here we construct fermionic all-to-all Floquet quantum circuits of random four-body gates designed to capture key features of SYK dynamics. Our circuits can be built using local ingredients in Majorana devices, namely, charging-mediated interactions and braiding Majorana zero modes. This offers an analog-digital route to SYK quantum simulations that reconciles all-to-all interactions with the topological protection of Majorana zero modes, a key feature missing in existing proposals for analog SYK simulation. We also describe how dynamical, including out-of-time-ordered, correlation functions can be measured in such analog-digital implementations by employing foreseen capabilities in Majorana devices.

TT 1.13 Mon 13:00 H10

Symplectic topological Kondo effect — •Elio Koenig[1], Jukka Vayrynen[2], and Guangjie Li[2] — [1]Max-Planck-Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany — [2]Purdue University, West Lafayette, IN 47907-2036, USA

The topological Kondo effect describes the stable, strongly coupled, non-Fermi liquid state obtained by screening a topological quantum dot, a so-called Majorana Cooper pair box, by means of external metallic leads. The symmetry group describing this exotic Kondo effect is the orthogonal group of rotations of real Majorana fermions. In this talk, I am going to present a symplectic topological Kondo effect, which, crucially, does not rely on the presence of Majorana modes. As I present in detail, this system can be implemented by coupling leads to a quantum dot consisting of a floating conventional s-wave superconductor coupled to spinful fermionic zero modes, as obtained e.g., in arrays of 1D topological insulators. Combining the solution of this problem at strong coupling with known results from Bethe Ansatz and conformal field theory demonstrates that this model harbors emergent anyonic excitations, including Fibonacci anyons, depending on the number of external leads. Importantly, the non-trivial physics is stable to anisotropies in the coupling to different leads.

TT 2: Nanotubes, Nanoribbons and Graphene

Time: Monday 9:30–13:15 Location: H22

TT 2.1 Mon 9:30 H22

Magnetic field control of the Franck-Condon coupling of few-electron quantum states — Peter L. Stiller, Daniel R. Schmid, Alois Dirnaichner, and •Andreas K. Hüttel — Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany

The longitudinal vibration of a suspended carbon nanotube has been observed many times in low temperature transport spectra via distinct harmonic Franck-Condon sidebands. Typically, strong Franck-Condon coupling has been attributed to disorder-induced or deliberately targetted charge localization. Here, we present the observation of a strong, tunable coupling in an ultra-clean carbon nanotube with $N = 1$ or $N = 2$ electrons in the conduction band. The clean transport spectrum allows a tentative identification of the electronic base quantum states according to their valley quantum number. Interestingly, the Franck-Condon coupling strength g, as extracted from our data, both depends on the magnetic field and on the precise electronic quantum states participating in transport. While spin-dependent Franck-Condon phenomena have already been observed, our results clearly point towards a valley-dependent origin. As possible cause of this phenomenon, reshaping of the electronic wavefunction envelope by the magnetic field is discussed. A simple calculation demonstrates that variations of g as observed in the experiment can be reproduced by the theory, paving the way towards more realistic and detailed quantum-mechanical modelling.

TT 2.2 Mon 9:45 H22

Transparent low-temperature contacts to MoS_2 microtubes — •Robin T. K. Schock[1], Jonathan Neuwald[1], Matthias Kronseder[1], Simon Reinhardt[1], Luka Pirker[2], Maja Remškar[2], and Andreas K. Hüttel[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Solid State Physics Department, Institute Jožef Stefan,1000 Ljubljana, Slovenia

Even though synthesis procedures of transition metal dichalcogenide (TMDC) based nanotubes have been established for many years, the quantum transport properties remain largely unexplored to date. First low-temperature transort spectroscopy results clearly show Coulomb blockage at 300 mK [1]. However, the contact material still remains a limiting factor due to the Fermi level pinning near the conduction band. Recently, for planar MoS_2 materials [2], the use of bismuth improved room-temperature contact resistances drastically. Here we present first transport measurements on MoS_2 microtubes with bismuth contacts at millikelvin temperatures. Our MoS_2 tubes are grown via a chemical transport reaction, yielding diameters down to 7 nm and lengths up to several millimeters. After transfering the tubes onto a Si/SiO_2 substrate, contacts are deposited using electron beam lithography. The resulting devices show Coulomb blockade, with in many cases, a transition from transparent conduction into a band gap. Disorder, compared with previous scandium-based devices, is significantly reduced.

[1] S. Reinhardt *et al.*, Phys. Stat. Sol. RRL **13**, 1900251 (2019)
[2] P. C. Shen *et al.*, Nature 593, **211** (2021).

TT 2.3 Mon 10:00 H22

Topological transitions in dc+ac-driven superconductor nanotubes — •Vladimir M. Fomin[1] and Oleksandr V. Dobrovolskiy[2] — [1]Institute for Integrative Nanosciences, Leibniz IFW Dresden, 01069 Dresden — [2]Superconductivity and Spintronics Laboratory, Nanomagnetism and Magnonics, Faculty of Physics, University of Vienna, 1090 Vienna

A complex interplay of the patterns of superconducting screening currents with the 3D geometry unveils a plethora of emerging effects in the dynamics of topological defects in curved 3D superconductor nanoarchitectures [1]. We discuss topological transitions in the dynamics of vortices and slips of the phase of the order parameter in open superconductor nanotubes under a modulated dc+ac transport current [2]. Relying upon the time-dependent Ginzburg-Landau equation, we reveal two voltage dynamics regimes. The first regime with a pronounced first harmonic in the FFT spectrum of the induced voltage occurs when the dominant area of the open tube is in the superconducting or normal state. The second regime entails a rich FFT spectrum of the induced voltage because of the complex interplay between the dynamics of vortices/phase slips and the screening currents. Our findings represent novel dynamical states in superconductor open nanotubes, in particular, paraxial and azimuthal phase-slip regions, their branching and coexistence with vortices, and allow for their control by superimposed dc+ac current stimuli.

[1] V. M. Fomin, O. V. Dobrovolskiy, Appl. Phys. Lett. **120**, 090501 (2022)
[2] V. M. Fomin, R. O. Rezaev, O. V. Dobrovolskiy, Scientific Reports **12**, accepted (2022)

TT 2.4 Mon 10:15 H22

Graphene nanomembranes as valleytronic devices — •Nikodem Szpak[1], Walter Ortiz[2,3], and Thomas Stegmann[3] — [1]Fakultät für Physik, Universität Duibsurg-Essen, Duisburg, Germany — [2]Instituto de Investigacion en Ciencias Basicas y Aplicadas, Universidad Autonoma del Estado de Morelos, Cuernavaca, Mexico — [3]Instituto de Ciencias Fisicas, Universidad Nacional Autonoma de Mexico, Cuernavaca, Mexico

We investigate the electronic transport in graphene nanoelectromechanical resonators (GrNEMS), known also as graphene nanodrums or nanomembranes. We demonstrate that these devices, despite small values of strain, between 0.1 and 1%, can be used as efficient and robust valley polarizers and filters. Their working principle is based on the pseudomagnetic field generated by the strain of the graphene membrane. They work for ballistic electron beams as well as for strongly dispersed ones and can be also used as electron beam collimators due to the focusing effect of the pseudomagnetic field. We show additionally that the current flow can be estimated by semiclassical trajectories which represent a computationally efficient tool for predicting the functionality of the devices.

[1] W. Ortiz, N. Szpak, T. Stegmann, arXiv:2202.01739 (2022), submitted

TT 2.5 Mon 10:30 H22

Quantum interference in graphene by dynamic strain — •Christian Glasenapp, Pai Zhao, Marta Prada, Lars Tiemann, and Robert h. Blick — Center for Hybrid Nanostructures, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We exploit surface acoustic waves (SAW) as a time-dependent strain wave that propagates through graphene [1] and study its influence on the weak localization (WL) phenomenon at 4 Kelvin. WL is a quantum interference effect that occurs due to the wave nature of charge carriers. In the case of graphene, it can be characterized by inelastic scattering and elastic inter- and intravalley scattering [2]. We fabricated interdigital transducers (IDTs) on a piezoelectric $LiNbO_3$ substrate, which can be actuated by a radiofrequency (RF) signal to generate a SAW. A large sheet of CVD-grown monolayer graphene was transferred onto the substrate and a Hall bar was patterned in the path of the SAW. In low-field magnetotransport measurements without SAW we observe a well-defined WL effect. When we launch a SAW that strains the graphene layer, WL becomes progressively suppressed with increasing SAW intensity. In this presentation we will show how SAW-induced dynamic strain affects the scattering mechanisms of WL.

[1] P. Zhao et al., Appl. Phys. Lett. 116, 103102 (2020)
[2] E. McCann et al., Phys. Phys. Lett. 97, 146805 (2006)

TT 2.6 Mon 10:45 H22

Tunable geometric phase in graphene quantum dots with spin-orbit coupling — •Dario Bercioux[1,2], Diego Frustaglia[3], and Alessandro De Martino[4] — [1]Donostia International Physics Center (DIPC), Manuel de Lardizbal 4, E-20018 San Sebastián, Spain — [2]IKERBASQUE, Basque Foundation for Science, Euskadi Plaza, 5, 48009 Bilbao, Spain — [3]Departamento de Física Aplicada II, Universidad de Sevilla, E-41012 Sevilla, Spain — [4]Department of Mathematics, City, University of London, London EC1V 0HB, United Kingdom

We show how chiral states in circular graphene *pn* junctions subject to normal magnetic fields and strong proximitized spin-orbit coupling can mimic those of propagating spin carriers in semiconducting quantum rings. We derive the effective one-dimensional Hamiltonian governing the spin dynamics of the zero-mode and calculate the associated geometric phase. We find that for a given polarity of the junction, it exists a special point in parameter space where the spin is fully polarized along the radial direction in the graphene plane. We further propose a quantum-Hall interferometer where these features can be readily identified.

TT 2.7 Mon 11:00 H22

Effective short distance interacting Hamiltonians for higher Landau levels in graphene — •Nikolaos Stefanidis[1] and Inti Sodemann[2,1] — [1]Max-Planck Institute for the Physics of Complex Systems, D-01187 Dresden, Germany — [2]Institut für Theoretische Physik, Universität Leipzig, D-04103 Leipzig, Germany

We study the many body problem in graphene in the quantum Hall regime. Although dominated by Coulomb interactions, short range corrections can select among the degenerate ground states. For the $N = 0$ Landau level (LL) their importance has been demonstrated [1,2] and recent work[3] suggests that this remains true in the $N = 1$ LL . In this talk, we will present results on effective Hamiltonians with $N \neq 0$. We analyse the point group symmetries of graphene and find the Hamiltonians dictated by those.

[1] M. Kharitonov, Phys. Rev. B 85, 155439 (2012)
[2] I. Sodemann, A. H. MacDonald, Phys. Rev. Lett. 112, 126804 (2014)
[3] Fangyuan Yang et al., Phys. Rev. Lett. 126, 156802 (2021)

TT 2.8 Mon 11:15 H22

Massless Dirac fermions with time-dependent magnetic barriers — •Nico Leumer[1] and Wolfgang Häusler[2] — [1]IPCMS, CNRS, University of Strasbourg, France — [2]University of Augsburg, Germany

Potential barriers controlled by gate electrodes, as common for 2D-electron gases, are inefficient to guide graphene carriers, due to the Klein tunneling phenomenon. One well known way out consists in using inhomogeneous magnetic fields [1]. However, when considering temporal variations, fundamental differences arise between electric and magnetic fields. While to good approximation the former can be treated on its own, time dependent magnetic fields always will induce electric fields of comparable strengths, according to Maxwell's equations. Following Ref. [2] we report on the complete analytical solution for transmission through a weakly, ω-periodically modulated magnetic barrier, homogeneous along the y-direction, accounting for side bands that appear at energies $E \pm \omega$ in first order perturbation theory. Inherently, magnetic fields generalize the scattering problem to two dimensions. We find that sideband transport requires the static barrier to be permeable, while momentum conservation imposes new, independent conditions for complete reflection.

[1] A. De Martino, L. Dell'Anna, R. Egger, PRL 98, 066802 (2007)
[2] M. Büttiker, R. Landauer, PRL 49, 1739 (1982)

15 min. break

TT 2.9 Mon 11:45 H22

Measuring correlated phases in encapsulated bilayer graphene via graphite contacts — •Isabell Weimer, Anna Seiler, and Thomas Weitz — 1st Physical Institute, Faculty of Physics, University of Göttingen, Friedrich-Hund-Platz 1, Göttingen 37077, Germany

Encapsulation of graphene in hexagonal Boron Nitride (hBN) as well as the addition of graphite top and bottom gates to the sample have been central to a lot of the research done on graphene in the recent years. This has allowed the observation of multiple new correlated phases including Stoner metals [1-3], correlated insulators [1] and superconductivity [2] at large electric fields in trigonal warped bilayer graphene.

The extent to which the phase space of Bernal bilayer graphene can be even further explored is amongst other parameters limited by the maximum electric field and thus by the maximum values of gate voltages that can be applied to the sample without breaking through the dielectric. With the aim of increasing these maximum voltages, we have explored the method of using graphite contacts to contact bilayer graphene flakes within van-der-Waals heterostructures [1]. Using graphite contacts instead of commonly used 1D edge contacts [4] removes the necessity to etch into the hBN flakes, which had previously been a limiting factor for the applied electric fields.

[1] A. M. Seiler et al., arXiv:2111.06413 (2021)
[2] H.Zhou et al., Science 375, 774 (2022)
[3] S. C. de la Barrera et al., arXiv:2110.13907 (2021)
[4] L.Wang et al., Science 342, 614 (2013)

TT 2.10 Mon 12:00 H22

Mapping electrostatically tunable bands in twisted double bilayer graphene in magnetic fields — •Yulia Maximenko[1,2], Marlou Slot[1,3], Sungmin Kim[1,2], Daniel Walkup[1], Evgheni Strelcov[1], En-Min Shih[1,3], Dilek Yildiz[1,2], Steven Blankenship[1], Kenji Watanabe[4], Takashi Taniguchi[4], Yafis Barlas[5], Paul Haney[1], Nikolai Zhitenev[1], Fereshte Ghahari[6], and Joseph Stroscio[1] — [1]NIST MD USA — [2]U of Maryland USA — [3]Georgetown U DC USA — [4]NIMS Tsukuba Japan — [5]U of Nevada-Reno NV USA — [6]George Mason U VA USA

After the first demonstration of superconductivity in magic-angle twisted bilayer graphene (MATBG), 2D moiré superlattices proved to be valuable systems for band engineering and studying correlated quantum phases. An imposed periodic potential can drive a crystal into a flat-band phase facilitating strong electron-electron interactions. In MATBG, flat bands appear only at a few precise values of the twist angle. In contrast, small-angle twisted double bilayer graphene (TDBG) can be tuned in and out of the correlated regime using electrostatic fields in a continuous range of twist angles. Local probe studies are key to avoid the common complication of angle disorder. Here we employ scanning tunneling microscopy and electrostatic gating to study TDBG with atomic spatial and high energy resolution in magnetic fields up to 15 T. We observe Landau quantization and map out the TDBG band structure in response to the applied electric field. We use theoretical modeling of the effects of displacement fields, Berry curvature, and magnetic fields to support our experimental findings.

TT 2.11 Mon 12:15 H22

Novel correlated phases near the van Hove singularity in Bernal bilayer graphene — •Anna Seiler[1], Fan Zhang[2], and Thomas Weitz[1] — [1]1st Physical Institute, Faculty of Physics, University of Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [2]Department of Physics, University of Texas at Dallas, Richardson, TX, 75080, USA

Diverging density of states offers a unique opportunity to explore a wide variety of correlated phases in low dimensional systems. Graphene few-layers can host electric-field controlled Lifshitz transitions and concomitant van-Hove-singularities in the density of states. Here, we present the observation of experimental signatures consistent with various interaction-driven phases in trigonally warped Bernal bilayer graphene including the fractional metals of Stoner type (1-3). More prominently, we have found a Chern-insulating phase that emerges at finite densities in between two Lifshitz transitions and even survives at zero magnetic field (1). This phase is consistent with a topologically nontrivial Wigner-Hall crystalline phase, i.e., an electron crystal with a quantized Hall conductance as originally proposed at finite magnetic fields in 1989 (4). Evidently, our discovery shows that the reproducible, tunable, and simple Bernal bilayer graphene is a fertile ground for exploring new, rich, and intricating many-body physics.

[1] A. M. Seiler et al., arXiv:2111.06413 (2021)
[2] H. Zhou et al., Science 375, 774 (2022)
[3] S. C. de la Barrera et al., arXiv:2110.13907413 (2021)
[4] Z. Tešanović, F. Axel, B. I. Halperin, Phys. Rev. B 39, 8525 (1989)

TT 2.12 Mon 12:30 H22

Towards quantum transport mesaurements on encapsulated rhombohedrally stacked multilayer graphene — •Monica Kolek Martinez de Azagra and Thomas Weitz — 1. Physikalische Institut, Georg August Universität Göttingen

In the recent past flat band multilayer graphene systems have become an experimental playground to explore a plethora of highly correlated many body phenomena such as superconductivity, topological insulators and ferromagnetic phases. However, so far the broad range of phenomena across the different systems, i.e., bilayer, twisted bilayer and rhombohedral trilayer graphene, still hold open questions to the origins and physical limitations of these phenomena. To further investigate these phenomena, we prepare high quality encapsulated multilayer graphene samples, using a variety of techniques such as Raman spectroscopy, scanning near field microscopy, atomic force microscopy and the dry transfer method with the goal to study these samples through magneto quantum transport measurements in the milli Kelvin regime.

TT 2.13 Mon 12:45 H22

Effective mass measurements near electric field controlled Lifshitz transitions in trigonally warped bilayer graphene — •Martin Statz[1], Anna Seiler[1], Francesca Falorsi[1], Jonas Pöhls[1], Kenji Watanabe[2], Takashi Taniguchi[3], and R. Thomas Weitz[1] — [1]Univ. of Göttingen, Göttingen, Germany — [2]Research Cent. for Funct. Mater., Tsukuba, Japan — [3]Int. Cent. for Mater. Nanoarchitectonics, Tsukuba, Japan

Various spontaneous symmetry broken phases such as Stoner ferromagnetism, spin-polarized superconductivity, a quantum anomalous Hall octet and a topologically non-trivial Wigner-Hall crystal phase have recently been reported in bilayer graphene (BLG). Since these interaction-driven phenomena are dictated by the ratio of the Coulomb and kinetic energy of carriers, they can be promoted by the formation of flat bands and a divergent density of states (DoS) near Lifshitz transitions (LT). Trigonally warped BLG at low vertical displacement fields (D-field) and carrier densities ($\sim 10^{11}$ cm^{-2}) displays one centre and three off-centre Dirac cones in each valley and therefore offers a rich playground for correlated phases (CP) by inducing charge density and D-field driven LT. Insights on the renormalized bandstr. and eff. masses of carriers near such LT will foster a deeper understanding of the formation of these CP. Here, we report on our status on eff. mass measurements via T-dep. (1.9-25 K) Shubnikov-de Haas osc. in the vicinity of charge density and D-field driven LT in trigonally warped BLG. To minimize effects from pot. disorder, we encapsulate BLG in hex. boron-nitride and employ graphite contacts and graphite gates.

TT 2.14 Mon 13:00 H22

Ising superconductivity induced from valley symmetry breaking in twisted trilayer graphene — •Tobias Stauber[1] and Jose Gonzalez[2] — [1]Instituto de Ciencia de Materiales de Madrid, CSIC — [2]Instituto de Estructura de la Materia, CSIC

We show that the e-e interaction induces a strong breakdown of valley symmetry in twisted trilayer graphene, just before the superconducting instability develops in the hole-doped material. We analyze this effect by means of an atomistic self-consistent Hartree-Fock approximation, which is a sensible approach as the Fock part becomes crucial to capture the breakdown of symmetry. This effect allows us to reproduce the experimental observation of the Hall density, including the reset at 2-hole doping. Moreover, the breakdown of valley symmetry has important consequences for the superconductivity, as it implies a reduction of symmetry down to the C3 group. This leads to spin-splitting with respect to the two different valleys, suggesting Ising superconductivity and leading to a Paul-violation with a factor 2-3 as seen in experiments [1]. We also find spin-layer locking which might explain the strong-coupling limit of superconductivity seen in general moiré-samples. We stress that the breakdown of symmetry down to C3 and subsequent spin-valley and spin-layer locking may be shared by other materials with valley symmetry breaking.

[1] J. González and T. Stauber, arXiv:2110.11294

TT 3: Superconductivity: Properties and Electronic Structure

Time: Monday 9:30–13:00 Location: H23

TT 3.1 Mon 9:30 H23

Is lead really a prototypical type I superconductor? New results on the phase diagram at ultra-low temperatures — Thomas Gozlinski, Qili Li, Rolf Heid, Jörg Schmalian, and •Wulf Wulfhekel — Karlsruhe Institute of Technology

Superconductors are classified by their behavior in a magnetic field into type I, which transitions from a superconducting Meissner to a normal state at the critical field and type II, which have an additional Shubnikov phase consisting of magnetic vortices with one magnetic flux quantum, each. For type I superconductors of finite lateral dimensions, the transition to the normal state is, however, known to occur locally in form of domains in the so-called intermediate Landau state. Basis for this classification are thermodynamic considerations near the critical temperature and a single band description of superconductivity. Although bulk lead (Pb) is classified as a prototypical type I superconductor, we surprisingly observe single and multi-flux quanta vortices in the intermediate state at temperatures far below the critical temperature using a 25 mK scanning tunneling microscope hand in hand with a complex superconducting behaviour of the two distinct Fermi surfaces of Pb. By probing the quasiparticle local density of states (LDOS) inside the vortices and comparison with quasi-classical simulations based on DFT band-structure calculations, we identify the Caroli-de-Gennes-Matricon states of the two superconducting bands of Pb and are consequently able to determine their winding number.

TT 3.2 Mon 9:45 H23

High-precision impedance measurements near the Berezinski-Kosterlitz-Thouless transition in strongly disordered superconductors — •Lea Pfaffinger[1], Alexander Weitzel[1], Thomas Huber[1], Klaus Kronfeldner[1], Lorenz Fuchs[1], Sven Linzen[2], Evgeni Il'ichev[2], Nicola Paradiso[1], and Christoph Strunk[1] — [1]University of Regensburg, Germany — [2]Leibniz Institute of Photonic Technology, Jena, Germany

We investigate the Berezinskii-Kosterlitz-Thouless (BKT) transition - a vortex induced topological phase transition - in 3 nm thin atomically layer deposited NbN films. The samples are placed inside a RLC-resonator, whose design enables us to perform AC measurements of the superfluid stiffness J_s and four-probe current-voltage (IV) characteristics in the same cooling cycle. In contrast to earlier experiments, we observe a sharp discontinuous jump of J_s at the BKT transition temperature T_{BKT}. Comparison of the J_s and the DC resistance measurements reveal quantitative agreement of both T_{BKT} and T_{c0}. Powerlaw exponents extracted of IV characteristics agree quantitatively with J_s and calculations based on renormalization group. Surprisingly, if a DC current is added to the rf-drive, $J_s(I)$ reaches a pronounced maximum before dropping sharply to zero at a current much smaller than the pair breaking critical current. This behaviour may be tentatively explained as a cut-off of the BKT renormalisation flow by the current.

TT 3.3 Mon 10:00 H23

Prediction of ambient-pressure superconductivity in ternary hydride PdCuH$_x$ — •Riccardo Vocaturo[1], Cesare Tresca[2], Giacomo Ghiringhelli[3], and Gianni Profeta[2,4] — [1]IFW-ITF, Dresden, Germany — [2]Università degli studi dell'Aquila, L'Aquila, Italy — [3]Politecnico di Milano, Milano, Italy — [4]CNR-SPIN, L'Aquila, Italy

We present an ab initio study of the ternary hydride PdCuH$_x$, a parent compound of the superconducting PdH, at different hydrogen content (x=1,2). We investigate its structural, electronic, dynamical, and superconducting properties, demonstrating that, at low hydrogen content, the system is not a superconductor above 1K; however, the highly hydrogenated structure is a strongly coupled superconductor. We give a solid rationale for the unusual increase of the superconducting critical temperature in hydrogenated palladium when alloyed with noble metals (Cu, Ag, and Au), as observed in Stritzker's experiments in 1972 but never investigated with modern experimental and theoretical techniques. We highlight the important role played by H-derived phonon modes at intermediate frequencies, dynamically stabilized by anharmonic effects, as they strongly couple with states at the Fermi level. We hope that the present results will stimulate additional experimental investigations of structural, electronic, and superconducting properties of hydrogenated palladium-noble metal alloys. Indeed, if confirmed, these compounds could be considered a novel class of superconducting hydrides, showing different coupling mechanisms, which can be exploited to engineer new ambient-pressure superconductors.

TT 3.4 Mon 10:15 H23

Theory of spin-excitation anisotropy in the nematic phase of FeSe obtained from RIXS measurements — •Andreas Kreisel[1], Peter Hirschfeld[2], and Brian M. Andersen[3] — [1]Institut für Theoretische Physik, Universität Leipzig — [2]Department of Physics, University of Florida, Gainesville — [3]Niels Bohr Institute, University of Copenhagen

Recent resonant inelastic x-ray scattering (RIXS) experiments have detected a significant high-energy spin-excitation anisotropy in the nematic phase of the enigmatic iron-based superconductor FeSe [1], whose origin remains controversial. We apply an itinerant model previously used to describe the spin-excitation anisotropy as measured by neutron scattering measurements [2], with magnetic fluctuations included within the RPA approximation. The calculated RIXS cross section exhibits overall agreement with the RIXS data [3], including the high energy spin-excitation anisotropy such that the picture of a localized Heisenberg model does not need to be evoked in order to explain the experimental data.

[1] X. Lu et al., Nat. Phys. (2022)
[2] T. Chen et al. Nat. Mater. **18**, 709 (2019)
[3] A. Kreisel, P. J. Hirschfeld, B. M. Andersen, Frontiers in Physics **10**, 859424 (2022)

TT 3.5 Mon 10:30 H23

Local measurements of (super-)conducting microstructure in $Rb_xFe_{2-y}Se_2$ — •Donald M Evans[1], Stephan Krohns[1], Dorina Croitori[2], Vladimir Tsurkan[1,2], and István Kézsmárki[1] — [1]Experimental Physics V, University of Augsburg, 86135 Germany — [2]Institute of Applied Physics, MD 2028 Chisinau, Moldova.

There are many reports on the bulk coexistence of competing orders in iron-based superconductors. In some of these systems, such as $RbFe_2Se_2$, this is because even single crystals spontaneously phase separate into a superconducting phase made up of micron scale islands, within an antiferromagnetic host matrix. Such phase coexistence makes any bulk data challenging to interpret and, rather, requires local measurement techniques.

In this work, we use low-temperature conducting atomic force microscopy (cAFM) to map the local current response of the superconducting islands in $RbFe_2Se_2$. Below T_c ($\sim 32K$) these islands show large current values, as expected for a superconductor. Unexpectedly, there is no distinct change in these current values when heating through Tc: rather, the high currents persist within the islands until they becoming as insulating as the bulk matrix at $\sim 150K$. This enhanced conductivity vanishes in response to external magnetic fields. This implies that the reported bulk Tc is the temperature at which the superconductivity is strong enough to connect the islands, i.e. the percolation limit, while the superconductivity within individual islands persists to higher temperatures. This work shows the strength of cAFM to understand the local properties of inhomogeneous superconductors.

TT 3.6 Mon 10:45 H23

Cascade of collapsed phases in $SrNi_2P_2$ and $CaKFe_2As_2$ under various strain conditions — •Adrian Valadkhani[1], Shuyang Xiao[2], Igor Mazin[3], Seok-Woo Lee[2], Paul Canfield[4], and Roser Valenti[1] — [1]Goethe University, Frankfurt am Main, Germany — [2]University of Connecticut, Connecticut, United States — [3]George Mason University, Fairfax, USA — [4]Iowa State University, Ames, United States

Most of crystalline solids have a maximum recoverable strain of less than 1%. Further strain will cause plastic deformation or fractures. In the current work we present $SrNi_2P_2$, whose maximum recoverable compressive strain is $\sim 14\%$ and tensile is $\sim 6\%$. These widespread values of strain are realizable due to a double lattice collapse-expansion mechanism. The ab initio density functional theory calculations are in very good agreement with the experiment[1,2]. Instead of the usual uncollapsed to collapsed tetragonal transition for the generic tetragonal 122s, a second transition to an orthorhombic superstructure is observed. By a detailed investigation of the electronic and geometric structures for various strains, and substitutions of the Sr, Ni, (and /) or P from first principles, we are able to give a deeper insight in the theory description of this doubly lattice collapse-expansion mechanism. Within this framework we will also discuss structural phases in $CaKFe_2As_2$ under varios strain conditions.

This work is support by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) for funding through TRR 288.

[1] Nano Lett. 2021, 21, 19, 7913
[2] Phys. Rev. B 56, 13796 (1997)

TT 3.7 Mon 11:00 H23

3DSC - A new dataset of superconductors including crystal structures — •Timo Sommer, Roland Willa, Jörg Schmalian, and Pascal Friederich — Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

More than 100 years after the discovery of superconductivity in mercury, the search for new superconducting materials still remains challenging. In contrast to most other phenomena, making theoretical predictions about the superconductivity of a certain material is extremely difficult, due to the need to model the comparably tiny energy gain of the superconducting phase, compared to the other energy scales of the problem. Data-driven methods, in particular machine learning, are well-known for finding complex patterns in existing datasets. In the case of superconductors, the use of data science tools is to date slowed down by a lack of accessible data. Here we present a new and publicly available superconductivity dataset ("3DSC"), featuring the critical temperature T_c of superconducting materials additionally to tested non-superconductors. In contrast to existing databases such as the SuperCon database, the 3DSC contains not only the chemical composition, but also the approximate three-dimensional crystal structure of each material. We perform machine learning experiments which show that access to this structural information improves the prediction of the critical temperature T_c. Additionally, we provide ideas for further research to improve the 3DSC in multiple ways. We argue that expanding and developing the 3DSC is a promising direction towards the reliable prediction of new superconductors using machine learning.

15 min. break

TT 3.8 Mon 11:30 H23

Control of the critical temperature of a superconductor/chiral magnet heterostructure — •Julius Grefe[1], Jannis Willwater[1], Rodrigo de Vasconcellos Lourenço[2], Markus Etzkorn[2,3], Stefan Süllow[1], and Dirk Menzel[1,3] — [1]IPKM, TU Braunschweig, Germany — [2]IAP, TU Braunschweig, Germany — [3]LENA, TU Braunschweig, Germany

Recently, theory has predicted that spin valves consisting of a superconducting film and a magnetic substrate exhibiting a non-collinear spin structure can be controlled via the proximity effect by changing the spin orientation of the magnet. The critical temperature T_c of a thin superconducting Nb film on top of a magnetic MnSi substrate is supposed to be altered when the spin helix vector switches from the inplane to the out-of-plane direction [1]. We have prepared substrates for molecular beam epitaxy from MnSi single crystals. After preparation the surface roughness has been investigated by AFM and TEM and is in the order of 1 nm. Afterwards, a 20 nm superconducting Nb thin film has been deposited on top of the MnSi substrate. In dependence of the orientation of the external magnetic field and, thus, the direction of the spin helix vector in the MnSi substrate, we observe a change of T_c in the Nb film. To distinguish between the influence of the helix on T_c and pure geometry effects, we compare the result with observations on a Nb film deposited on an isostructural but non-magnetic CoSi substrate.

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

TT 3.9 Mon 11:45 H23

Gate controlled switching in A15 and non-centrosymmetric superconducting devices — •Jennifer Koch, Leon Ruf, Simon Haus, Roman Hartmann, Elke Scheer, and Angelo Di Bernardo — Universität Konstanz, Konstanz, Germany

Gate-controlled superconducting devices have become of great interest for the development of energy-efficient hybrid superconductor/semiconductor computing architectures. The idea behind this technology stems from the recent discovery that superconducting devices can be controlled electrically with the application of a gate voltage [1-3]. We investigate gate-controlled switching devices made of A15 and non-centrosymmetric superconductors like Nb_3Ge (A15) and $Nb_{0.18}Re_{0.82}$ (non-centrosymmetric). These materials promise a low switching voltage due to their disordered structure and high spin-orbit coupling and should therefore be more suitable for the realization of devices working at voltages comparable to those used for the control of CMOS transistors.

[1] G. de Simoni et al., Nat. Nanotechnol. 13, 802 (2018)
[2] F. Paolucci et al. , Nano Lett. 18, 4195 (2018)
[3] F. Paolucci et al., Phys. Rev. Applied 11, 024061 (2019)

TT 3.10 Mon 12:00 H23

Fano interference of the Higgs response and CDW fluctuations in cuprate high-T_c superconductors — •Liwen Feng[1,2,3], Hao Chu[1,2,4], Sergey Kovalev[5], Lukas Schwarz[1], Tao Dong[6], Min-Jae Kim[1,2,3], Gideok Kim[1], Gennady Logvenov[1], Bernhard Keimer[1], Dirk Manske[1], Nanlin Wang[6], Jan-Christoph Deinert[5], and Stefan Kaiser[1,2,3] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]4th Physics Institute, University of Stuttgart, Stuttgart, Germany — [3]Institute of Solid State and Materials Physics, Technical University Dresden, Dresden, Germany — [4]Quantum Matter Institute, University of British Columbia, Vancouver, Canada — [5]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [6]International Center for Quantum Materials, Peking University, Beijing, China

Cuprate high-T_c superconductors exhibit a rich phase diagram due to the presence of multiple orders. The interplay of these orders is difficult to access directly by experimental probes. Here, we introduce phase-resolved Higgs spectroscopy, i.e. THz driven amplitude oscillations of the superconducting order parameter. We find a Fano interference of the driven Higgs mode with charge density fluctuations in superconducting $La_{2-x}Sr_xCuO_2$ ($0.05 \leq x \leq 0.25$). The interference manifests itself as a distinct jump in the phase of the driven Higgs oscillation, which we characterize in an extensive doping- and magnetic field-dependent study. As such, Higgs spectroscopy provides a novel and direct view on the intriguing interplay of charge density fluctuations and superconductivity in high-T_c cuprates.

TT 3.11 Mon 12:15 H23

Clarifying the origin of CDW and finding the routes to superconductivity in Ti-Se systems. — •Andrii Kuibarov, Yulia Shemerliuk, Alexander Fedorov, and Sergey Borisenko — IFW Dresden, Deutschland

Two-dimensional chalcogenides have gained renewed attention mainly because of the novel topological properties observed in single crystals and thin films. Although $TiSe_2$ has been intensively researched over the last 20 years, the true nature of its charge density waves (CDW) state remains controversial. Several different theories have been proposed during these years to explain CDW formation: Fermi surface nesting, Jahn-Teller effect and excitonic insulator.

We try to answer this question using high-resolution ARPES measurements and DFT calculations for different Ti-Se systems: $TiSe_2$, Cu_xTiSe_2, TiSeS. We show that the CDW state does disappear at various Cu-doping in Cu_xTiSe_2 as it was thought before.

TT 3.12 Mon 12:30 H23

Superconductivity in the type-I Weyl semimetal trigonal-$PtBi_2$ — •Arthur Veyrat[1], Valentin Labracherie[1], Federico Caglieris[1,2], Jorge I. Facio[1], Grigory Shipunov[1], Jeroen van der Brink[1,3], Bernd Büchner[1,3], Saicharan Aswartham[1], and Joseph Dufouleur[1,4] — [1]Leibniz Institute for Solid State and Materials Research (IFW Dresden), Dresden, Germany — [2]CNR-SPIN, Genova, Italy — [3]Department of Physics, TU Dresden, Dresden, Germany — [4]Center for Transport and Devices, TU Dresden, Dresden, Germany

Symmetry breaking in topological matter became a key concept in condensed matter physics to unveil novel electronic states. In particular, the interplay between topology and superconductivity in topologically non-trivial materials is of great interest for the study of unconventional superconducting states. In this talk, I present DFT calculations showing a type-I Weyl semimetal band structure in trigonal $PtBi_2$. We also evidenced, via transport measurements, that single crystals of trigonal $PtBi_2$ are superconducting ($T_c \sim 600mK$), which represents the first unambiguous report of bulk superconductivity in a type-I Weyl semimetal. We further characterized the superconductivity in exfoliated thin flakes of trigonal $PtBi_2$ to be 2-dimensional, up to 126 nm, and we evidence a Berezinskii-Kosterlitz-Thouless transition in flakes up to 60nm thick, with $T_{BKT} \sim 310mK$. This discovery makes trigonal $PtBi_2$ a very interesting platform to study the interplay between low dimensional superconductivity and topology, into relatively thick and easily fabricated samples.

TT 3.13 Mon 12:45 H23

Vortex inductance as a directional probe of Lifshitz invariants in synthetic Rashba-superconductors — Lorenz Fuchs[1], Denis Kochan[1], Christian Baumgartner[1], Simon Reinhardt[1], Sergei Gronin[2], Geoffrey C. Gardner[2], Tyler Lindemann[2], Michael J. Manfra[2], Christoph Strunk[1], and •Nicola Paradiso[1] — [1]University of Regensburg — [2]Purdue University

In type II superconductors, the magnetic field penetrates the sample in quantized units of flux, which correspond to vortices in the superfluid. To save condensation energy, vortices tend to be pinned to defects. If these are sharp, the pinning potential $U(\vec{r})$ is harmonic near the vortex core, where it mirrors the superfluid density $|\Psi(\vec{r})|^2$. In this work, we show that in 2D Rashba superconductors the combination of spin orbit interaction and in-plane magnetic field leads to an anisotropic squeezing of the vortex core. This, in turn, produces a strong enhancement of the pinning strength, which can be measured by vortex inductance measurements. To this end, we developed a technique to measure small inductances which is compatible with the application of both DC bias and strong magnetic fields. Vortex inductance is sensitive to the curvature of the pinning potential along the direction perpendicular to the supercurrent. Thus, our method enables a full tomography of the vortex core, obtained by measuring inductance as a function of the angle between current and field. Our results can be interpreted as the effect of the spin orbit-induced Lifshitz invariant term in the Ginzburg-Landau free energy.

TT 4: Many-Body Quantum Dynamics 1 (joint session DY/TT)

Time: Monday 10:00–12:45 Location: H20

TT 4.1 Mon 10:00 H20

Squeezed-field path integral method for fermionic superfluid systems — •Dapeng Li — Luruper Chaussee 149, Gebäude 69 22761 Hamburg

We develop a squeezed field path integral method for fermionic superfluid systems including BCS superconductors and unconventional superfluid systems. In this method, the squeezing parameters of the Bogoliubov transformation for fermions become dynamical variables representing bosonic collective excitations on superfluid systems. Using this method, we analyze the spectral function of the single particle excitations for BCS superconductors. We demonstrate that, as a main consequence of the method, a bosonic branch corresponding to the Higgs mode appears as a sideband branch, in addition to the single particle excitation branches obtained from the BCS mean-field approximation. Moreover, we show that our framework can also be applied to low-energy excitations of systems with unconventional orders.

TT 4.2 Mon 10:15 H20

Suppression of inter-band heating for random driving — •Hongzheng Zhao[1,2], Johannes Knolle[2,3,4], Roderich Moessner[1], and Florian Mintert[2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Imperial College London, London, United Kingdom — [3]Technical University of Munich, Munich, Germany — [4]Munich Center for Quantum Science and Technology, Munich, Germany

Heating to high-lying states strongly limits the experimental observation of driving induced non-equilibrium phenomena, particularly when the drive has a broad spectrum. Here we show that, for entire families of structured random drives known as random multipolar drives, particle excitation to higher bands can be well controlled even away from a high-frequency driving regime. This opens a window for observing drive-induced phenomena in a long-lived prethermal regime in the lowest band. Reference: arXiv:2201.08130

TT 4.3 Mon 10:30 H20

Anomalous hydrodynamics and exact quantum scars in frustration-free Hamiltonians — •Jonas Richter and Arijeet Pal — University College London, UK

We study the interplay between quantum scarring and weak Hilbert-space fragmentation in a class of one-dimensional spin-1 frustration-free projector Hamiltonians, known as deformed Motzkin chain. We show that the particular form of the projectors causes the emergence of disjoint Krylov subspaces, with an exact quantum scar being embedded in each subspace, leading to slow growth of entanglement and localized dynamics for specific out-of-equilibrium initial states. Focusing on infinite temperature, we unveil that spin transport is subdiffusive, which we corroborate by simulations of constrained stochastic cellular automaton circuits. Compared to dipole moment conserving systems, the deformed Motzkin chain belongs to a different universality class with distinct dynamical transport exponent and only polynomially many Krylov subspaces. Based on J. Richter and A. Pal, Phys. Rev. Research 4, L012003 (2022).

TT 4.4 Mon 10:45 H20

Influence functional of quantum many-body systems — •Alessio Lerose, Michael Sonner, Julian Thoenniss, and Dmitry Abanin — University of Geneva, Switzerland

Feynman-Vernon influence functional (IF) was originally introduced to describe the effect of a quantum environment on the dynamics of an open quantum system. We apply the IF approach to describe quantum many-body dynamics in isolated spin systems, viewing the system as an environment for its local subsystems. While the IF can be computed exactly only in certain many-body models, it generally satisfies a self-consistency equation, provided the system, or an ensemble of systems, are translationally invariant. We view the IF as a fictitious wavefunction in the temporal domain, and approximate it using matrix-product states (MPS). This approach is efficient provided the temporal entanglement of the IF is sufficiently low. We illustrate the versatility of the IF approach by analyzing several models that exhibit a range of dynamical behaviors, from thermalizing to many-body localized, in both Floquet and Hamiltonian settings. The IF approach offers a new lens on many-body non-equilibrium phenomena, both in ergodic and non-ergodic regimes, connecting the theory of open quantum systems theory to quantum statistical physics.

TT 4.5 Mon 11:00 H20

Transition from localized to uniform scrambling in locally hyperbolic systems — •Mathias Steinhuber, Juan-Diego Urbina, and Klaus Richter — University of Regensburg, Regensburg, Germany

A major signature of Quantum Chaos is the fast scrambling of quantum correlations, quantified by the exponential initial (pre-Ehrenfest time) growth of out-of-time-order correlators (OTOCs) and by their later saturation. As previously shown by [1] and [2], there is a significant difference in the short time dynamics of the OTOCs in integrable systems around hyperbolic fixed points depending on the initial state being localized or uniform (high-temperature). In these cases, the exponential regime is given respectively by twice the instability-exponent 2λ or only once the stability-exponent λ of the hyperbolic fixed point. We show that a local wave-packet can have a clear *dynamical* transition between these two reported exponential-regions within the pre-Ehrenfest-time regime. Thus, the question arises on how to decide, based on the properties of the hyperbolic fixed point which of the two scenarios applies in each particular situation.

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

2 Xu, T., Scaffidi, T. & Cao, X. Does Scrambling Equal Chaos? Phys. Rev. Lett. 124, 140602 (2020).

15 min. break

TT 4.6 Mon 11:30 H20

Optimal route to quantum chaos in the Bose-Hubbard model — Lukas Pausch[1,2], 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

The dependence of the chaotic phase of the Bose-Hubbard Hamiltonian [1,2] on particle number N, system size L and particle density is investigated in terms of spectral and eigenstate features. We analyze the development of the chaotic phase as the limit of infinite Hilbert space dimension is approached along different directions, and show that the fastest route to chaos is the path at fixed density $n \lesssim 1$ [3]. The limit $N \to \infty$ at constant L leads to a slower convergence of the chaotic phase towards the random matrix theory benchmarks. In this case, from the distribution of the eigenstate generalized fractal dimensions, the ergodic phase becomes more distinguishable from random matrix theory for larger N, in a similar way as along trajectories at fixed density.

[1] L. Pausch *et al.*, Phys. Rev. Lett. 126, 150601 (2021)
[2] L. Pausch *et al.*, New J. Phys. 23, 123036 (2021)
[3] L. Pausch *et al.*, arxiv:2205.04209

TT 4.7 Mon 11:45 H20

Observation of phase synchronization and alignment during free induction decay of quantum spins with Heisenberg interactions — •Jürgen Schnack[1], Heinz-Jürgen Schmidt[2], Christian Schröder[3], and Patrick Vorndamme[1] — [1]Universität Bielefeld — [2]Universität Osnabrück — [3]Fachhochschule Bielefeld

Equilibration of observables in closed quantum systems that are described by a unitary time evolution is a meanwhile well-established phenomenon apart from a few equally well-established exceptions. Here we report the surprising theoretical observation that integrable as well as non-integrable spin rings with nearest-neighbor or long-range isotropic Heisenberg interaction not only equilibrate but moreover also synchronize the directions of the expectation values of the individual spins (New J. Phys. 23 (2021) 083038). We highlight that this differs from spontaneous synchronization in quantum dissipative systems. In our numerical simulations, we investigate the free induction decay (FID) of an ensemble of up to N = 25 quantum spins with s = 1/2 each by solving the time-dependent Schrödinger equation numerically exactly. Our findings are related to, but not fully explained by conservation laws of the system. The phenomenon very robust against for instance random fluctuations of the Heisenberg couplings. Synchronization is not observed with strong enough symmetry-breaking interactions such as the dipolar interaction and is also not observed in closed-system classical spin dynamics.

TT 4.8 Mon 12:00 H20

Long-lived coherence in driven spin systems: from two to infinite spatial dimensions — •Walter Hahn[1,2,3] and Viatcheslav Dobrovitski[2,4] — [1]Fraunhofer IAF, Fraunhofer Institute for Applied Solid State Physics, Freiburg, Germany — [2]QuTech, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands — [3]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, Innsbruck, Austria — [4]Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands

Long-lived coherences, emerging under periodic pulse driving in the disordered ensembles of strongly interacting spins, offer immense advantages for future quantum technologies but the physical origin and the key properties of this phenomenon remain poorly understood. We theoretically investigate this effect in ensembles of different spatial dimensionality, and predict existence of the long-lived coherences in all such systems, from two-dimensional to infinite-dimensional, which are of particular importance for quantum sensing and quantum information processing. We explore the transition from two to infinite dimensions and show that the long-time coherence dynamics in all dimensionalities is qualitatively similar, although the short-time behavior is drastically different exhibiting dimensionality-dependent singularity

TT 4.9 Mon 12:15 H20

A Flow Equation Approach to Many-Body Localisation — •Steven Thomson — Dahlem Centre for Complex Quantum Systems, Freie Universität Berlin

Many-body localisation is a fascinating example of a scenario in which interacting quantum systems isolated from their environments can fail to thermalise, usually due to some form of disorder. Key to our understanding of this enigmatic phase of matter are emergent conserved quantities known as local integrals of motion (LIOMs, or l-bits), which prevent thermalisation from occurring. In this talk, I will present a powerful new numerical method known as the tensor flow equation technique ideally suited for computing LIOMs.

I will demonstrate how this method can be used to compute the integrals of motion in a variety of different systems, including disorder-free potentials and models of spinful fermions. I will show how this method gives an insight into the nature of many-body localisation in these different models, with LIOMs that retain a strong 'fingerprint' of the underlying potential, and will show that in some cases the method can also predict the onset of a delocalised phase. I will end by outlining promising future applications of the method, including to periodically driven and dissipative systems.

TT 4.10 Mon 12:30 H20

Towards a dictionary between JT gravity and periodic orbit theory — •Torsten Weber, Fabian Haneder, Juan-Diego Urbina, and Klaus Richter — University of Regensburg, Germany

Periodic orbit theory is a far reaching development of the semiclassical methods where the most fundamental signatures of the quantum nature of closed systems, like the discreteness of their energy spectrum, emerges from interference between amplitudes constructed from the classical properties of periodic solutions [1]. This conceptual basis, leading to the celebrated Gutzwiller trace formula, has provided impressive achievements from quantum transport to atomic physics and multi-particle scattering. In particular, together with the necessary existence of periodic orbit bunching in ergodic systems, it has lead to an understading of the emergence of universal spectral correlations in chaotic systems, the BGS conjecture [2].
We report our progress in studying how a loss of information (characterized by a coarse graining of classical bunches of orbits) at the level of the trace formula implies the emergence of genus-like expansions with formally the same structure as the solution of JT quantum gravity found in [3]. Our work thus gives convincing hints toward a possible dictionary between quantum-gravitational and periodic orbit objects and concepts.

[1] See e.g. F. Haake, Quantum Signatures of Chaos, Springer, 2000
[3] S. Müller et al., Phys. Rev. E 72, 046207 (2005)
[3] P. Saad, S. Shenker, D. Stanford, arXiv:1903.11115

TT 5: Frustrated Magnets – Spin Liquids

Time: Monday 15:00–17:00 Location: H10

Invited Talk TT 5.1 Mon 15:00 H10

Dynamics of visons and thermal Hall effect in perturbed Kitaev models — •Aprem Joy and Achim Rosch — Institute for Theoretical Physics, University of Cologne, Cologne, Germany

A vison is an excitation of the Kitaev spin liquid which carries a $\mathbb{Z}_2$ gauge flux. While immobile in the pure Kitaev model, it becomes a dynamical degree of freedom in the presence of perturbations. We study an isolated vison in the isotropic Kitaev model perturbed by a small external magnetic field h, an offdiagonal exchange interactions Γ and a Heisenberg coupling J. In the ferromagnetic Kitaev model, the dressed vison obtains a dispersion linear in Γ and h and a fully universal low-T mobility, $\mu = 6v_m^2/T^2$, where v_m is the velocity of Majorana fermions. In contrast, in the antiferromagnetic Kitaev model interference effects preclude coherent propagation and an incoherent Majorana-assisted hopping leads to a T-independent mobility. The motion of a single vison due to Heisenberg interactions is strongly suppressed for both signs of the Kitaev coupling. Vison bands induced by h in the AFM Kitaev model are topological and contribute to the thermal Hall effect.

TT 5.2 Mon 15:30 H10

Microscopic modeling of the Kitaev spin liquid candidates $Li_3Co_2SbO_6$ and $Na_3Co_2SbO_6$ under uniaxial strain — •Willi Roscher, Huimei Liu, Jeroen van den Brink, and Oleg Janson — Leibniz Institute for Solid State and Materials Research IFW Dresden, 01069 Dresden, Germany

We have studied the magnetic properties of two Kitaev spin liquid candidates $Li_3Co_2SbO_6$ [1] and $Na_3Co_2SbO_6$ [2] under strain effect by using a microscopic density functional theory (DFT)-based analysis. Previous theoretical work [3] suggested that honeycomb cobaltates are promising candidates to realize the Kitaev spin liquid phase and can be driven there by lattice engineering. Following this conjecture, we simulate the effect of uniaxial strain along the c-axis. Low-energy tight-binding Hamiltonians were first obtained using DFT calculations and Wannier projections. Using the DFT-estimated parameters, we calculate the exchange parameters of the extended Kitaev-Heisenberg model. In this way, we get insights into the magnetic behavior of these materials under uniaxial strain. A small reduction of the trigonal splitting is found for tensile strain. Even though the strain is insufficient to drive the compounds into the spin liquid phase, the non-Kitaev terms are greatly suppressed in the investigated strain range. Our quantitative calculations shed light for the materialization of the Kitaev model.

[1] M. Stratan *et al.*, New J. Chem. **43**, 13545 (2019)
[2] L. Viciu *et al.*, J. Solid State Chem. **180**, 1060 (2007)
[3] H. Liu *et al.*, Phys. Rev. Lett. **125**, 047201 (2020)

TT 5.3 Mon 15:45 H10

Thermal conductivity of a new quantum Kagome antiferromagnet $YCu_3(OH)_{6.5}Br_{2.5}$ — •Xiaochen Hong[1,2], Mahdi Behnami[2], Long Yuan[3], Boqiang Li[3], Wolfram Brenig[4], Bernd Büchner[2], Yuesheng Li[3], and Christian Hess[1,2] — [1]Bergische Universität Wuppertal — [2]IFW-Dresden — [3]Huazhong University of Sci. and Tech., Wuhan, China — [4]TU Braunschweig

Herbertsmithite $ZnCu_3(OH)_6Cl_2$ has long been studied as the archetypal quantum Kagome antiferromagnet whose ground state is anticipated to be a spin liquid. However, there is no consensus on the ground state properties of Herbertsmithite, in particular whether a spin gap exist or not, due to its Cu/Zn site mixing effect that distorts the Kagome plane.

Here we report low temperature thermal conductivity measurements of a newly synthesized quantum Kagome antiferromagnet $YCu_3(OH)_{6.5}Br_{2.5}$. We observe a downwards deviation of its thermal conductivity κ from a standard phononical power-law temperature dependence beyond a characteristic temperature T^* and a systematic enhancement of this deviation upon application of a magnetic field. Furthermore, up to 16 T no residual κ/T occurs. Our findings imply that the thermal conductivity is dominated by phonons in the mK range, excluding itinerant gapless excitations contributing to it. We interpret the suppression of κ in magnetic field as a consequence of enhanced scattering of the phonons off magnetic fluctuations beyond T^*. Our analysis favors a small gap in the magnetic excitations, which is be suppressed by the magnetic field.

TT 5.4 Mon 16:00 H10

Spinless fermions in a $\mathbb{Z}_2$ gauge theory on a triangular ladder — •Wolfram Brenig — Institute for Theoretical Physics, Technical University Braunschweig, D-38106 Braunschweig, Germany

A study of spinless matter fermions coupled to a constrained $\mathbb{Z}_2$ lattice gauge theory on a triangular ladder is presented. The triangular unit cell and the ladder geometry lead to a physics different from that on the square lattice. In the static case, even and odd gauge theories are identical. The gauge field dynamics is strongly influenced by the absence of periodic boundary conditions, rendering the deconfinement-confinement process a crossover in general and a quantum phase transition only for decorated electric coupling. At finite doping and in the static case, distinct flux phases can be identified versus magnetic energy. As for the square lattice, a single transition into a confined fermionic phase is found versus electric coupling, however dimer resonances in the confined phase are second order processes only. Global scans of the quantum phases in the intermediate coupling regime are provided.

TT 5.5 Mon 16:15 H10

Nesting instability of gapless U(1) spin liquids with spinon Fermi pockets in two dimensions — •Wilhelm Krüger and Lukas Janssen — Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität 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. 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.

TT 5.6 Mon 16:30 H10

Frustrated magnetism in pyrochlore rare earth materials: a pseudofermion-FRG study — •Bernhard Wortmann — Univeristät zu Köln — Köln — Deutschland

The family of rare earth pyrochlore materials is intensely scrutinized in the search for quantum spin-ice and quantum spin liquid phases. On the theoretical side, an initial focus has been to explore frustration phenomena in Heisenberg models in order to model the low temperature physics of these materials. It has, however, become increasingly clear that one has to also consider the sometime dominating effect of anisotropic exchange interactions, such as bond-directional Kitaev or Gamma couplings. In this talk, I will discuss the phase diagram of the Heisenberg-Kitaev-Gamma model on the pyrochlore lattice, calculated for S=1/2 quantum spins using the pseudofermion functional renormalization group. The rich phase diagram obtained when considering the competition of antiferromagnetic and ferromagnetic exchanges allows us to identify coupling regimes where we find agreement with recent neutron scattering experiments.

TT 5.7 Mon 16:45 H10

Competition between X-Cube and Toric Code in three dimensions — •Matthias Mühlhauser[1], Kai Phillip Schmidt[1], Julien Vidal[2], and Matthias Reimund Walther[1] — [1]Institute for Theoretical Physics I, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [2]Sorbonne Université, CNRS, Laboratoire de Physique Théorique de la Matière Condensée, LPTMC, F-75005 Paris, France

We investigate the competition of the X-Cube model with the 3D Toric Code using high-order series expansions. We determine the complete phase diagram, which interestingly consists of four regions, i.e. apart from the topologically ordered Toric-Code phase and the X-Cube fracton phase we find two regions which are adiabatically connected to classical spin-liquid phases.

[1] M. Mühlhauser, K. P. Schmidt, J. Vidal, M. R. Walther. SciPost Phys. 12, 069 (2022)

TT 6: Kondo Physics, f-Electron Systems and Heavy Fermions

Time: Monday 15:00–18:15 Location: H22

TT 6.1 Mon 15:00 H22

Zooming in on heavy fermions in Kondo lattice models — Bimla Danu[1], Zihong Liu[1], Fakher Assaad[1], and •Marcin Raczkowski[2] — [1]Institut für Theoretische Physik und Astrophysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany — [2]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, 97074 Würzburg, Germany

Resolving the heavy fermion band in the conduction electron momentum resolved spectral function of the Kondo lattice model (KLM) is challenging since, in the weak coupling limit, its spectral weight is exponentially small. To alleviate this limitation we consider a composite fermion operator, consisting of a conduction electron dressed by spin fluctuations that shares the same quantum numbers as the electron. Using auxiliary field quantum Monte Carlo simulations we show that for the SU(2) spin-symmetric model on the square lattice at half filling, the quasiparticle residue of the composite fermion tracks the Kondo coupling J_k. This result holds down to $J_k/W = 0.05$, with W the bandwidth, and confirms that magnetic ordering, present below $J_k/W = 0.18$, does not destroy the heavy quasiparticle. We also study the spectral function of the composite fermion in the ground state and at finite temperatures, for SU(N) generalizations of the KLM, as well as for ferromagnetic Kondo couplings, and compare our results to analytical calculations in the limit of high temperatures, large-N, large-S and large J_k.

TT 6.2 Mon 15:15 H22

Two-channel Kondo effect in locally non-centrosymmetric systems — •Daniel Hafner — Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

A scalable model is presented, which shows that two-channel Kondo (2CK) physics is possible in centrosymmetric crystals, in which the spin-orbit (SO) energy splitting α of conduction electron states is stronger than the hopping parameter t between an inversion symmetric pair of them. The potential difference introduced by the SO coupling effectively suppresses the hopping and disentangles the conduction states into two channels, allowing them to independently couple to impurity spins. If the impurity sites are located on inversion centers, the identical Kondo coupling strengths lead to a symmetrical 2CK effect below the Kondo temperature T_{2CK}. Since the coupling between sectors is still present, the impurity spin is eventually fully quenched by the entangled part of the conduction electrons in a single-channel Kondo effect below T_{1CK}. For $\alpha/t > \sqrt{2}$, a temperature region $T_{2CK} > T > T_{1CK}$ with dominant 2CK physics is found. If the impurities are not located on inversion centers, the resulting channel-asymmetric 2CK model introduces a third temperature scale. Below this, each of two inversion-symmetric impurity sites is screened by one of the two channels, creating a Fermi liquid made up of two types of Kondo singlets linked by inversion symmetry. The similarity of the presented 2CK model to the well established 2CK effect in quantum dots is discussed as well as possible candidate materials like the locally non-centrosymmetric heavy-fermion superconductor $CeRh_2As_2$.

TT 6.3 Mon 15:30 H22

Spin chain on a metallic surface: Dissipation-induced order vs. Kondo entanglement — •Bimla Danu[1], Matthias Vojta[2], Tarun Grover[3], and Fakher F. Assaad[1] — [1]Institut für Theoretische Physik und Astrophysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany — [2]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany — [3]Department of Physics, University of California at San Diego, La Jolla, CA 92093, USA

We study the physics of an antiferromagnetic spin-1/2 chain Kondo coupled to a two dimensional metal as realized, for example, by depositing an array of magnetic adatoms on a metallic surface with scanning tunneling microscopy (STM) methods. Based on a field theoretical perturbative approach we show that at weak Kondo coupling this system maps onto a spin-1/2 chain coupled to a dissipative Ohmic bath. We argue that in this limit the dissipation induces long-range antiferromagnetic order along the spin chain. Using auxiliary field quantum Monte-Carlo simulations we show that the spin chain as a function of the Kondo coupling exhibits a quantum phase transition from an antiferromagnetic phase to a paramagnetic heavy fermi liquid phase. Since the heavy quasiparticle is not destroyed in the magnetic phase and at the critical point, this quantum phase transition falls in a Hertz-Millis-Moriya type quantum criticality. We discuss the relevance of our results in the context of STM experiments of magnetic adatom chains on metallic surfaces.

TT 6.4 Mon 15:45 H22

Quasiparticle critical slowing down in a heavy-fermion system — •Chia-Jung Yang[1], Kristin Kliemt[2], Cornelius Krellner[2], Johann Kroha[3], Manfred Fiebig[1], and Shovon Pal[1,4] — [1]Department of Materials, ETH Zurich, 8093 Zurich, Switzerland — [2]Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt, Germany — [3]Physikalisches Institut and Bethe Center for Theoretical Physics, Universität Bonn, 53115 Bonn, Germany — [4]School of Physical Sciences, National Institute of Science Education and Research, HBNI, Jatni, 752 050 Odisha, India

Critical slowing down (CSD) is a universal phenomenon in phase transitions. A system, after suffering an initial perturbation, takes a very long time to return to its equilibrium state. While CSD is universally observed in the dynamics of bosonic excitations, it is not observed to occur for fermionic excitations. This is because of the half-integer nature of the fermionic spin. In this contribution, we show a fermionic CSD in the heavy-fermion (HF) compound $YbRh_2Si_2$ (YRS) by using phase-sensitive terahertz time-domain spectroscopy (THz-TDS). THz-TDS has recently been introduced as a novel tool to investigate the quasiparticle dynamics across quantum phase transition (QPT) in HF compounds [1–3]. We see that near the QPT in YRS, the build-up of spectral weight towards the Kondo temperature $T_K^* = 25\,K$ is followed by a logarithmic rise of the quasiparticle excitation rate on the heavy-Fermi-liquid side below 10 K. A critical two-band HF liquid theory shows that this is indicative of fermionic CSD, the softening of the HF quasiparticle dispersion.

TT 6.5 Mon 16:00 H22

Pressure tuning of the low-temperature states of $CeRh_2As_2$ — •Meike Pfeiffer[1], Konstantin Semeniuk[2], and Elena Hassinger[1,2] — [1]Technische Universität München, 85748 Garching, Germany — [2]Max Planck Institut für chemische Physik fester Stoffe, 01187 Dresden, Germany

$CeRh_2As_2$ is a heavy-fermion superconductor with a centrosymmetric tetragonal crystal structure lacking local inversion symmetry at the Ce sites. It presents two-phase superconductivity with an exceptionally high ratio of critical field (> 15 T) to critical temperature ($T_c = 0.3\,K$). An additional phase can be observed below 0.4 K, believed to be a quadrupole-density wave (QDW) order. We conducted an electrical resistivity study of $CeRh_2As_2$ down to 30 mK applying hydrostatic pressure up to 3 GPa. We find that under pressure the Kondo coherence peak shifts linearly to higher temperature at a rate of 10 K/GPa. The QDW order is highly sensitive to lattice compression and gets fully suppressed at about 0.7 GPa. The superconducting T_c decreases with a significantly lower rate suggesting no influence of QDW on superconductivity. The upper critical fields show an anisotropic behaviour: for $H \parallel$ c it decreases, whereas for $H \parallel$ a,b it increases for pressures up to ≈ 0.9 GPa and then also decreases. We relate our observations to the change of the relevant energy scales, such as Kondo temperature, Rashba spin-orbit coupling, and interlayer hopping.

TT 6.6 Mon 16:15 H22

The quadrupole density wave and its interplay with superconductivity in $CeRh_2As_2$: A thermodynamic study — •Pavlo Khanenko[1,2], Daniel Hafner[1], Robert Küchler[1], Jacintha Banda[1], Thomas Lühmann[1], Javier F. Landaeta[1], Florian Bärtl[3], Tommy Kotte[3], Joachim Wosnitza[2,3], Christoph Geibel[1], Seunghyun Khim[1], Elena Hassinger[1,4], and Manuel Brando[1] — [1]Max Planck Institute for Chemical Physics of Solids, Germany — [2]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, Germany — [3]Hochfeld-Magnetlabor Dresden (HLD-EMFL) and Würzburg-Dresden Cluster of Excellence, Germany — [4]Technical University Munich, Germany

The heavy-fermion $CeRh_2As_2$ is a rare case of multi-phase superconductor ($T_c = 0.26\,K$) located in the vicinity of a quantum critical point. Two different superconducting (SC) phases are observed for a magnetic field applied along the c-axis of the tetragonal locally-non-centrosymmetric crystalline structure. The upper critical field along c-axis ($B \parallel c$) is huge, $B_{c2} = 14\,T$, but with field within the basal ab-plane ($B \perp c$) only a single SC phase is observed with $B_{c2} = 2\,T$. Thermodynamic measurements have detected another non-magnetic phase transition at $T_0 = 0.4\,K$ which was interpreted as a quadrupole-density-wave (QDW) state. Here, we present new zero-field-cooled and field-cooled specific heat and thermal expansion measurements on a single crystal of $CeRh_2As_2$ with $B \parallel c$ and $B \perp c$. These allow to extend the phase diagram for $B \parallel c$ and to discuss the interplay between the SC and QDW states.

15 min. break

TT 6.7 Mon 16:45 H22

Heavy quasiparticles in Fermi surface and electronic instabilities in the heavy-fermion superconductor $CeRh_2As_2$ — •Evrard-Ouicem Eljaouhari and Gertrud Zwicknagl — Institut f. Mathemat. Physik, TU Braunschweig, Braunschweig, Germany

We present calculations of the heavy quasiparticles in the heavy-fermion compound $CeRh_2As_2$ which exhibts multi-phase superconductivity[1]. The narrow quasiparticle bands that are derived from the Ce-4f degrees of freedom are calculated by means of the Renormalized Band (RB) method. The RB scheme provides a framework for a realistic description of the coherent low-energy excitations in a Fermi liquid which combines material-specific ab-initio methods and phenomenological considerations in the spirit of the Landau theory of Fermi liquids. The central focus of the present study is the role played by the non-symmorphic lattice structure and the consequences of the Crystalline Electric Field (CEF) which removes the orbital degeneracy of the Ce 4f states. We conjecture that the quasi-quartet CEF ground state in combination with pronounced nesting features of the Fermi surface may give rise to a quadrupole density wave [2].

This work is supported by the ANR-DFG program Fermi-NESt.

[1] S. Khim et al., Science 373, 1012 (2021)
[2] D. Hafner et al., Phys. Rev. X 12, 011023 (2022)

TT 6.8 Mon 17:00 H22

Muon spin rotation/relaxation studies on the heavy-fermion superconductor $CeRh_2As_2$ — •Seunghyun Khim[1], Manuel Brando[1], Oliver Stockert[1], Christoph Geibel[1], Zurab Guguchia[2], Robert Scheuermann[2], Debarchan Das[2], and Toni Shiroka[2] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany — [2]Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, Villigen PSI, Switzerland

We study magnetic and superconducting (SC) properties of the unconventional superconductor $CeRh_2As_2$ ($T_c \sim 0.3$ K) by means of muon spin rotation/relaxation (μSR) experiments. No clear evidence of oscillation is identified in zero-field μSR spectra down to 0.27 K while the relaxation rate moderately increases below ∼ 0.4 K. This could be associated with the suggested quadrupole-density-wave order at T_0 ≈ 0.4 K and the antiferromagnetic order at T_N ≈ 0.27 K. In weak transverse-field (TF) μSR measurements, a pronounced increase in the relaxation rate was observed in the SC state. The relaxation rate (σ_s), regarded as a direct measure of the magnetic penetration depth λ ($\sigma_s \propto 1 / \lambda^2$), almost flattens below $T/T_c \sim 0.2$, being strongly indicative of suppressed quasiparticle excitations. TF-μSR measurements under 2 T reveal a power-law-like T-dependent relaxation rate in the normal state, indicating critical fluctuations. Furthermore, this relaxation rate increases with fields in both the normal and SC state, implying unusual magnetism. Our observations suggest $CeRh_2As_2$ to have a nearly fully-gapped SC behavior in the vicinity of a peculiar quantum critical point.

TT 6.9 Mon 17:15 H22

Anisotropy of resistivity and magnetotransport in $CeRh_2As_2$ — •Konstantin Semeniuk, Seunghyun Khim, and Elena Hassinger — Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

The recently discovered heavy-fermion superconductor $CeRh_2As_2$ exhibits an intriguing low-temperature phase diagram containing two superconducting states [1], a quadrupole density wave order [2], and an antiferromagnetic state [3]. The underlying mechanisms of such a behaviour are currently being explored. However, symmetry-induced Rashba spin-orbit effect, Kondo interaction and interlayer coupling have already emerged as the primary ingredients.

To quantify the electronic properties of the compound further, we conducted a comprehensive study of charge transport in $CeRh_2As_2$. Precise control over sample dimensions and current flow direction were achieved via focused ion beam micromachining of single crystals in a strain-free manner. Based on resistivity anisotropy measurements the three-dimensional character of the electronic structure is established. We also examine magnetoresistance and Hall effect for different orientations of magnetic field with respect to the lattice.

[1] J. Landaeta et al., Phys. Rev. X, accepted (2022)
[2] D. Hafner et al., Phys. Rev. X **12**, 011023 (2022)
[3] M. Kibune et al., Phys. Rev. Lett. **128**, 057002 (2022)

TT 6.10 Mon 17:30 H22

Influence of substrate clamping in epitaxial $EuPd_2Si_2$ thin films — •Sebastian Kölsch[1], Cornelius Krellner[1], Hans-Joachim Elmers[2], and Michael Huth[1] — [1]Goethe Universität, Frankfurt (Main) — [2]Johannes Gutenberg-Universität, Mainz

Europium-based ternary compounds, which crystallize in the tetragonal $ThCr_2Si_2$ structure, reveal a variety of interesting phenomena, which are attributed to strong electronic correlations and a competition between Kondo effect and the RKKY interaction. Recently $EuPd_2Si_2$ gained increased interest due to a temperature-driven valence transition from nearly Eu^{2+} above 200 K to Eu^{3+} below about 50 K. This rapid but continuous change of the Europium mean valence is accompanied by a relative change of the $EuPd_2Si_2$ a lattice constant by about -2 % reflecting the strong coupling of lattice and electronic degrees of freedom. For epitaxial thin films of this material the underlying substrate has to be taken into account. In this case the change of the lattice constants due to clamping to the substrate impacts the possible thermal expansion of the corresponding in-plane components. So far research has focused on optimizing single crystal growth conditions under different doping scenarios to tune the system into a critial endpoint. Epitaxial thin films instead offer the possibility to strain-engineer this correlated system by appliying biaxial strain to the thin film material upon cooling.

Here we present for the first time the successful growth of $EuPd_2Si_2$ as epitaxial thin film and report our recent results regardings its clearly distinct properties as compared to single crystals.

TT 6.11 Mon 17:45 H22

Theory of valence-band photoemission from Am metal — •Jindrich Kolorenc — Institute of Physics (FZU), Czech Academy of Sciences, Praha, Czech Republic

The 5f states in americium metal are generally agreed to be localized, similar to 4f states in lanthanides, being in a well-defined $5f^6$ configuration (Am^{3+}). In the same time, the valence-band photoemission spectrum [1,2] cannot be interpreted as a single set of multiplet transitions ($5f^6 \to 5f^5$) like in lanthanides [3], and a second set of multiplets ($5f^7 \to 5f^6$) has to be introduced [4]. Two mechanisms were suggested as a possible origin of these additional transitions: (i) Am^{2+} layer forming at the surface of the sample or (ii) a second screening channel for the 5f hole created during the photoemission process, with the second mechanism later determined as more likely [2]. Up to now, there does not seem to be a quantitative theory that would substantiate these empirical ideas. The best attempt to date [5] combined the DFT+DMFT method with a generalized Hubbard-I impurity solver, which reproduced the $5f^7 \to 5f^6$ part of the spectrum well, but it also generated a spurious 5f intensity at the Fermi level. Here I report a DFT+DMFT study employing a more accurate impurity solver (exact diagonalization) and demonstrate the mechanism leading to the $5f^7 \to 5f^6$ multiplets in the Am PES spectra.

[1] J. R. Naegele *et al.*, Phys. Rev. Lett. **52**, 1834 (1984)
[2] T. Gouder *et al.*, Phys. Rev. B **72**, 115122 (2005)
[3] J. K. Lang *et al.*, J. Phys. F: Met. Phys. **11**, 121 (1981)
[4] N. Mårtensson *et al.*, Phys. Rev. B **35**, 1437 (1987)
[5] A. Svane, Solid State Commun. **140**, 364 (2006)

TT 6.12 Mon 18:00 H22

Kondo systems with periodically driven dipole transitions — •Michael Turaev and Johann Kroha — Physikalisches Institut, Universität Bonn, Nußallee 12, 53115 Bonn, Germany

In this work, we study the effects of light irradiation on a magnetic impurity. The impurity is modelled by the single impurity Anderson model where the local impurity is coupled to the conduction electrons via dipole coupling. Therefore, the application of a strong laser field induces a time-periodic hybridization. This can be treated within Floquet Green's function method combined with the slave boson non-crossing approximation [1]. What we see is that the Kondo peak is robust against small driving strengths, and then it gets strongly suppressed when the driving strength increases. However, we find that the destruction of the Kondo effect occurs much faster in terms of driving strength compared to a situation where the energy level of the impurity is itself driven independently.

[1] B. H. Wu and J. C. Cao, Physical Review B81, 085327 (2010)

TT 7: Fluctuations, Noise, Magnetotransport, and Related Topics

Time: Monday 15:00–18:00 Location: H23

TT 7.1 Mon 15:00 H23

Large Hall and Nernst effect from chiral spin fluctuations — Kamil K. Kolincio[1], Max Hirschberger[2,3], and •Jan Masell[3,4] — [1]Gdansk Tech, Gdansk, Poland — [2]University of Tokyo, Tokyo, Japan — [3]RIKEN CEMS, Wako, Japan — [4]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Magnetic materials with tilted electron spins exhibit conducting behaviour that is explained by the geometrical Berry phase, driven by a chiral (left- or right-handed) spin-habit. Dynamical and nearly random spin fluctuations, with a slight trent towards left- or right-handed chirality, represent a promising route to realizing Berry-phase phenomena at elevated temperatures. [1] Here, we report thermoelectric and electric transport experiments on a triangular and on a slightly distorted kagomé lattice material, respectively. We show that the impact of chiral spin fluctuations is strongly enhanced for the kagomé lattice. Our modelling shows that the geometry of the kagomé lattice plays a crucial role as it helps to avoid cancellation of Berry-phase contributions already in the disordered (paramagnetic) state. Hence, the observations for the kagomé material contrast with theoretical models treating magnetization as a continuous field, and emphasize the role of lattice geometry on emergent electrodynamic phenomena.

[1] K. K. Kolincio, M. Hirschberger, J. Masell, S. Gao, A. Kikkawa, Y. Taguchi, T.-h. Arima, N. Nagaosa, Y. Tokura, PNAS 118, e2023588118 (2021)
[2] K. K. Kolincio et al., submitted

TT 7.2 Mon 15:15 H23

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 magnetoresistance has been reported for atomic contacts, interpreted as emerging magnetic ordering in small dimension, which is triggered by the vicinity of the respective bulk metals to a Stoner instability. 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 [6]. 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] Prestel et al., PRB 104, 115434 (2021)

TT 7.3 Mon 15:30 H23

Synchronization in Josephson photonics devices with shot noise — •Florian Höhe[1], Lukas Danner[1,2], Brecht Donvil[1], 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.

The intrinsic shot noise of the Josephson-photonics device inevitably diffuses the oscillators phase and requires an extension of the classical theory [3] describing locking and synchronization to the quantum regime. Here, the shot noise, which is linked to the Full Counting Statistics, induces phase slips. Injection locking and synchronization lead to a strong narrowing of the photon emission statistics.

[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., Phys. Rev. B 104, 054517 (2021).

TT 7.4 Mon 15:45 H23

Theory of difference frequency quantum oscillations — •Valentin Leeb[1] and Johannes Knolle[1,2,3] — [1]Department of Physics TQM, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom

Quantum oscillations (QO) describe the periodic variation of physical observables as a function of inverse magnetic field in metals. The Onsager relation connects the basic QO frequencies with the extremal areas of closed Fermi surface pockets, and the theory of magnetic breakdown explains the observation of sums of QO frequencies at high magnetic fields. Here we develop a quantitative theory of *difference frequency* QOs in metals with multiple Fermi pockets with parabolic or linearly dispersing excitations. We show that a non-linear interband coupling, e.g. in the form of interband impurity scattering, can give rise to otherwise forbidden QO frequencies which can persist to much higher temperatures compared to the basis frequencies. We discuss the experimental implications of our findings, for example, for materials with multifold fermion excitations.

TT 7.5 Mon 16:00 H23

General bounds of electronic shot noise in the absence of currents — Jakob Eriksson[1], •Matteo Acciai[1,2], Ludovico Tesser[1], and Janine Splettstoesser[1] — [1]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, S-412 96 Göteborg, Sweden — [2]University of Gothenburg, S-412 96 Göteborg, Sweden

We investigate the charge and heat electronic noise in a generic two-terminal mesoscopic conductor in the absence of the corresponding charge and heat currents. Despite these currents being zero, shot noise is generated in the system. We show that, irrespective of the conductor's details and the specific nonequilibrium conditions, the charge shot noise never exceeds its thermal counterpart, thus establishing a general bound [1]. Such a bound does not exist in the case of heat noise, which reveals a fundamental difference between charge and heat transport under zero-current conditions.

[1] Eriksson et al., Phys. Rev. Lett. 127, 136801 (2021)

15 min. break

TT 7.6 Mon 16:30 H23

Direct observation of vortices in an electron fluid — •Tobias Völkl[1], Amit Aharon-Steinberg[1], Arkady Kaplan[1], Arnab Pariari[1], Indranil Roy[1], Tobias Holder[1], Yotam Wolf[1], Alexander Meltzer[1], Yuri Myasoedov[1], Martin Huber[2], Binghai Yan[1], Gregory Falkovich[3], Leonid Levitov[4], Markus Hücker[1], and Eli Zeldov[1] — [1]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, Israel — [2]Departments of Physics and Electrical Engineering, University of Colorado Denver, Denver, USA — [3]Department of Physics of Complex Systems, Weizmann Institute of Science, Rehovot, Israel — [4]Department of Physics, Massachusetts Institute of Technology, Cambridge, USA

Strongly-interacting electrons in ultrapure conductors have been shown to display signatures of hydrodynamic behavior including negative nonlocal resistance and Poiseuille flow in narrow channels. Here we provide the first visualization of current vortices in an electron fluid. By utilizing a nanoscale scanning superconducting quantum interference device on a tip we image the current distribution in a circular chamber connected through a small aperture to a current-carrying strip in the high-purity type-II Weyl semimetal WTe_2. We find that vortices are present only for small apertures, whereas the flow is laminar (nonvortical) for larger apertures. Our findings suggest a novel mechanism of hydrodynamic flow in thin pure crystals: the spatial diffusion of electrons' momenta is enabled by small-angle scattering at the surfaces, instead of the routinely invoked electron-electron scattering.

TT 7.7 Mon 16:45 H23

Optical dipole orientation of interlayer excitons in $MoSe_2$-WSe_2 heterostacks — •Mirco Troue[1], Lukas Sigl[1], Manuel Katzer[2], Malte Selig[2], Florian Sigger[1], Jonas Kiemle[1], Johannes Figueiredo[1], Mauro Brotons-Gisbert[3], Brian Gerardot[3], Andreas Knorr[2], Ursula Wurstbauer[4], and Alexander Holleitner[1] — [1]TU Munich — [2]Technical University Berlin — [3]Heriot-Watt University — [4]University of Münster

Transition metal dichalcogenide monolayers exhibit strong light-matter interactions, which promotes them as ideal candidates for novel 2D optoelectronic applications. A vertical stacking into van der Waals heterostacks leads to the formation of long-lived interlayer excitons in adjacent layers. We present the far-field photoluminescence intensity distribution of interlayer excitons in $MoSe_2$-WSe_2 heterostacks as measured by back focal plane imaging in the temperature range between 1.7K and 20K. An analytical model describing the emission pattern from a dielectric heterostructure is used to obtain the relative contributions of the in- and out-of-plane transition dipole moments associated with the interlayer exciton photon emission. We determine the transition dipole moments for all observed interlayer exciton transitions to be $(99 \pm 1)\%$ in-plane for R- and H-type stacking, independent of the excitation power and therefore the density of the exciton ensemble in the experimentally examined range. Moreover, we discuss the limitations of the presented measurement technique to observe correlation effects for many-body states in dense ensembles of interlayer excitons.

TT 7.8 Mon 17:00 H23

Magnetic and transport behaviour of quasi 2D NiS_2 flakes — •Roman Hartmann[1], Mario Amado Montero[2], Elke Scheer[1], and Angelo Di Bernardo[1] — [1]Fachbereich Physik, Universität Konstanz, Germany — [2]Department of Physics, University of Salamanca, Spain

Spintronics with 2D materials is emerging as a new field which enables development of devices with novel functionality compared to their three-dimensional counterparts.

We have recently managed to cleave single crystal NiS_2 down to the quasi 2D limit despite it not being a layered material. Bulk NiS_2 is a Mott insulator that has an interesting magnetic structure with an antiferromagnetic phase below 39 K and weak ferromagnetic ordering with a Curie temperature of 29 K. [1]

In transport measurements of thin flakes we see an increase in conductivity compared to the bulk, presumably due to the presence of metallic surface states. The ferromagnetic transition is clearly visible as kinks in the R-T curves and R-H curves . With magnetic field applied there is a complex hysteretic behaviour in the resistance with a strong asymmetry with respect to the direction of the applied field.

As a next step we are also looking into coupling the NiS_2 flakes to 2D superconductors to create two-dimensional superconducting spintronic devices.

[1] T. Thio et al., Phys. Rev. B 52, 5 (1995)

TT 7.9 Mon 17:15 H23

Spectral properties of the herringbone lattice — •Miguel Angel Jiménez Herrera[1,2] and Dario Bercioux[2,3] — [1]Centro de Física de Materiales (CFM-MPC) Centro Mixto CSIC-UPV/EHU, 20018 Donostia-San Sebastian, Basque Country, Spain — [2]Donostia International Physics Center, 20018 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, Euskadi Plaza, 5, 48009 Bilbao, Spain

We investigate the spectral properties of a two-dimensional electronic lattice that belongs to a non-symmorphic space group. More specifically, we look at the herringbone lattice that is characterised by two sets of glide symmetries applied in two orthogonal directions. We describe the system using a tight-binding model with nearest neighbors divided into horizontal and vertical hopping terms. We find two non-equivalent Dirac cones inside the first Brillouin zone along a high-symmetry paths, among other features, which react to different perturbations applied to the Hamiltonian. These perturbations break the symmetries of the lattice: we begin by placing different onsite potentials in the lattice sites. We observe annihilation of Dirac cones into semi-Dirac cones and nodal lines along high symmetry paths. Finally, we perturb the system by applying a dimerization on the hoppings. We report a flow of Dirac cones inside the first Brillouin zone describing quasi-hyperbolic curves

TT 7.10 Mon 17:30 H23

Hierarchical equations of motions approach to the study of thermodynamic uncertainty relations — Salvatore Gatto and •Michael Thoss — Institute of Physics, Albert-Ludwigs-Universität Freiburg

Thermodynamic uncertainty relations (TUR) are cost-precision trade-off relations in transport systems, relating the fluctuations in the heat and particle currents to the reversibility of the operation regime. While some violations have been reported for the TUR in classical systems, it has been found out that the geometry of quantum non-equilibrium steady-states alone directly implies the existence of a general quantum TUR. In this contribution, we investigate the relationship between quantum effects and current fluctuations in quantum systems. The hierarchical equation of motion approach is employed, which allows a numerically exact simulation of nonequilibrium transport in general open quantum systems involving multiple bosonic and fermionic environments.

TT 7.11 Mon 17:45 H23

Bosonization for Q = 0 particle-hole excitations of 2D gapless fermions — •Sebastian Mantilla[1] and Inti Sodemann[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [2]Institut für Theoretische Physik, Universität Leipzig, 04103 Leipzig, Germany

Understanding the non-perturbative effects of strong interactions on gapless phases of fermions in two-spatial dimensions is one of the major challenges in quantum condensed matter physics. Bosonization in one- and higher-dimensional systems has successfully captured such effects, where the picture of excitations in higher dimensions consists of small deformations of the Fermi surface. We discuss an extension for gapless phases in fermionic systems (e.g., nodal semimetals, Dirac fermions), not describable by the previous formalism since the Fermi surface shrinks to a point and the deformation picture breaks down. The new picture consists of a collection of excitons that considers non-perturbative effects in the weak- and strong-coupling regimes. We apply the formalism in two cases involving interacting electrons in graphene: the corrections to the optical response of 2D free fermions in monolayer graphene, and the weak coupling instability due to electron-hole attractive interactions in bilayer graphene. Our results contribute to understanding the effects of strong interactions in gapless fermions and extend bosonization beyond the picture of Fermi surface deformations.

TT 8: Frustrated Magnets – Strong Spin-Orbit Coupling

Time: Monday 17:15–19:00 Location: H10

TT 8.1 Mon 17:15 H10

α-RuCl$_3$ probed by ultrasound under hydrostatic pressure — •Andreas Hauspurg[1,2], S. Zherlitsyn[1], T. Helm[1], T. Yanagisawa[3], V. Tsurkan[4], and J. Wosnitza[1,2] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), HZDR, Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Department of Physics, Hokkaido University, Sapporo, Japan — [4]Institute of Physics, University of Augsburg, Germany

As a prime candidate for a quantum spin liquid (QSL) in the frame of the Kitaev model, is the honeycomb material α-RuCl$_3$ of particular interest. Although α-RuCl$_3$ exhibits antiferromagnetic order below 7 K, it is considered as proximate to the QSL. The QSL features fractionalized quasiparticle excitations. A promising approach to investigate such excitations is to study the coupling between fractionalized quasiparticles and phonons. This affects the attenuation coefficient and the sound velocity of ultrasound. Our recent studies of the elastic properties of α-RuCl$_3$ show a promising path to unveil the unconventional physics of the debated QSL phase. Here, we present low-temperature results of the sound velocity and attenuation in external magnetic fields and under hydrostatic pressures. The observed anomalies in the acoustic properties and strong magnetoelastic couplings shed new light on the unconventional physics in this compound. At a pressure of 11.3 kbar the antiferromagnetic order is completely suppressed.

TT 8.2 Mon 17:30 H10

Fractional Excitation-induced Phonon Renormalization in α-RuCl$_3$ — •Adrian Merritt[1], Xiao Wang[1], Alexei Bosak[2], Luigi Paolasini[2], Alexandre Ivanov[3], Rolf Heid[4], and Yixi Su[1] — [1]Jülich Centre for Neutron Science JCNS-FRM II, Forschungszentrum Jülich GmbH, Garching, Germany — [2]European Synchrotron Radiation Facility (ESRF), Grenoble, France — [3]Institut Laue-Langevin, Grenoble, France — [4]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, Karlsruhe, Germany

The quantum spin liquid (QSL) phase is of immense interest to condensed matter physicists, and have been studied for decades. With a Kitaev model that is exactly solvable and gives a QSL ground state, more recent work has focused on the J_{eff}=1/2 materials and in particular, α-RuCl$_3$. Above the critical magnetic field B_c 7T and below T 6K there is evidence for the half-integer quantized plateau possibly arising from the fractional excitations in the QSL phase. Recent theoretical work has shown that the fractional excitations can induce phonon renormalization via the spin-lattice coupling, and would in particular affect the acoustic phonons near the zone boundary. Our measurements have focused on the phonon dispersion in α-RuCl$_3$ to observe this phonon renormalization effect in the putative QSL phase. We have been able to survey the acoustic phonons in the relevant scattering directions under magnetic fields using single crystals. We will discuss our results with a focus on examining the low-energy acoustic phonon branches we measured in comparison to published work as well as the observed phonon renormalization effect.

TT 8.3 Mon 17:45 H10

Quantum Monte Carlo simulations of generalized Kitaev models: applications to α-RuCl$_3$ — •Toshihiro Sato[1] and Fakher F. Assaad[1,2] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Germany

We introduce a phase pinning approach in the realm of the auxiliary field quantum Monte Carlo (QMC) algorithm that mitigates the severity of the negative sign problem inherent to QMC methods of frustrated spin systems [1]. This allows us to access high-temperature thermodynamic and dynamical properties of the aforementioned systems and, for instance, carry out exact QMC simulations in a window of temperatures relevant to experiments for various frustrated magnets. We use our method to carry out extensive simulations of thermodynamic properties under magnetic fields in generalized Kitaev models describing α-RuCl$_3$, and discuss the characteristic feature in the field-direction dependence of the magnetic susceptibility, the specific heat as well as the magnetotropic coefficient. Our numerical results allow for direct comparison with recent measurements of the magnetotropic coefficient in α-RuCl$_3$ [2].

[1] T. Sato and F. F. Assaad, Phys. Rev. B. 104, L081106 (2021)
[2] K. A. Modic et al., Nat. Phys. (2020)

TT 8.4 Mon 18:00 H10

RuCl$_3$: Phonon (Hall) transport and sibling compounds RuBr$_3$, RuI$_3$ — •David A S Kaib[1], Sananda Biswas[1], Stephen M Winter[2], Kira Riedl[1], Aleksandar Razpopov[1], Ying Li[3], Steffen Backes[4], Igor I Mazin[5], and Roser Valenti[1] — [1]Goethe-Universität, Frankfurt, Germany — [2]Wake Forest University, Winston-Salem, NC 27109, USA — [3]School of Physics, Xi'an Jiaotong University, Xi'an 710049, China — [4]Institut Polytechnique de Paris, Route de Saclay, 91128 Palaiseau, France — [5]George Mason University, Fairfax, VA 22030, USA

We present results of two studies related to the Kitaev candidate material RuCl$_3$:

Recent experimental studies have pointed to the presence of significant magnetoelastic coupling in RuCl$_3$ and have highlighted unusual thermal transport signatures under magnetic field. We compute the pseudospin-phonon coupling in RuCl$_3$ from first principles and use it to model the intrinsic thermal transport from phonons scattered by spin fluctuations. This includes both the longitudinal as well as the transversal (Hall) conductivity.

In the second part of the talk, we analyze two new sibling compounds to RuCl$_3$: RuBr$_3$ and RuI$_3$. While current samples show a bad metal behavior in RuI$_3$, our first principles calculations predict a Mott insulator close to the Mott-metal transition in the pristine parent compound, with a dominant Kitaev interaction and negligible Heisenberg exchange.

TT 8.5 Mon 18:15 H10

High-field ESR studies of the cubic Iridium hexahalide compounds $(NH_4)_2IrCl_6$ and K_2IrCl_6 — •Lakshmi Bhaskaran[1], Alexey N. Ponomaryov[2], Jochen Wosnitza[1,3], Nazir Khan[4], Alexander A. Tsirlin[4], Mike E. Zhitomirsky[5], and Sergei A. Zvyagin[1] — [1]Dresden High Magnetic Field Laboratory (HLD-EMFL) and Würzburg-Dresden Cluster of Excellence ct.qmat, Helmholtz-

Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Institute of Radiation Physics, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [3]Institut für Festkörper- und Materialphysik, TU Dresden, Dresden, Germany — [4]University of Augsburg, Augsburg, Germany — [5]University Grenoble Alpes, Grenoble, France

We report on high-field electron spin resonance studies of two iridium hexahalide compounds, $(NH_4)_2IrCl_6$ and K_2IrCl_6 [1]. In the paramagnetic state, our measurements reveal isotropic g-factors $g = 1.79(1)$ for the Ir^{4+} ions, in agreement with their cubic symmetries. Most importantly, in the magnetically ordered state, we observe two magnon modes with zero-field gaps of 11.3 and 14.2 K for $(NH_4)_2IrCl_6$ and K_2IrCl_6, respectively. Based on that and using linear spin-wave theory, we estimate the nearest-neighbor exchange couplings and anisotropic Kitaev interactions, $J_1/k_B = 10.3$ K, $K/k_B = 0.7$ K for $(NH_4)_2IrCl_6$, and $J_1/k_B = 13.8$ K, $K/k_B = 0.9$ K for K_2IrCl_6, revealing the nearest-neighbor Heisenberg coupling as the leading interaction term, with only a weak Kitaev anisotropy.
[1] L. Bhaskaran et al., Phys. Rev. B **104**, 184404 (2021).

TT 8.6 Mon 18:30 H10

Spin-orbit excitons in the j_{eff}=1/2 compound K_2IrCl_6 — •Philipp Warzanowski[1], Marco Magnaterra[1], Karolin Hopfer[1], Christoph Sahle[2], Marco Morreti Sala[3], Giulio Monaco[4], Petra Becker[5], Ladislav Bohatý[5], and Markus Grüninger[1] — [1]Inst. of Physics II, University of Cologne — [2]European Synchrotron Radiation Facility, Grenoble Cedex, France — [3]Dip. di Fisica, Politecnico di Milano, Italy — [4]Dip. di Fisica e Astronomia, Università di Padova, Italy — [5]Sect. Crystallography, Inst. of Geology and Mineralogy, University of Cologne

Spin-orbit entangled Mott insulators offer new playgrounds to explore novel ground states. Iridates with a t_{2g}^5 electron configuration are popular platforms to realize j_{eff} =1/2 systems due to the large cubic crystal field and strong spin-orbit coupling. Spectroscopies, RIXS in particular, show that thus far all iridates harbour non-cubic crystal field distortions, which turn the ground state away from an ideal j_{eff} = 1/2 state. In this context, the (globally) cubic compound K_2IrCl_6 is a promising candidate to host ideal j_{eff} = 1/2 moments. However, both RIXS and infrared spectroscopy show a splitting of the spin-orbit exciton. Within a single-site scenario, we extract a spin-orbit coupling λ = 435 meV and a non-cubic crystal field Δ = 60 meV, yielding a ground state of 99.8% j_{eff} = 1/2 character. To explore the origin of non-cubic distortions, we discuss the possible effects of i) librations [1], ii) the coupling to phonons, and iii) defects [2].
[1] N. Khan *et al.*, Phys Rev B **103**, 125158 (2021)
[2] S.-S. Bao *et al.*, Inorg. Chem. **57**, 13252 (2018)

TT 8.7 Mon 18:45 H10

Fragility of charge frustration in high-pressure CsW_2O_6 — •Pascal Reiss[1], Masahiko Isobe[1], and Hidenori Takagi[1,2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Department of Physics, The University of Tokyo, Bunkyo, Tokyo, Japan

The transition metal compound CsW_2O_6 represents an intriguing example of a pyrochlore structure at quarter filling. Starting from a nominal $W^{5.5+}$ oxidation state, the system suffers a metal-to-insulator transition around $T_c \approx 215$ K where a breathing distortion leads to the formation of regular molecular W_3 trimers with 2 localised electrons each, and a remaining W^{6+} site devoid of $5d$ electrons [1]. Recently, it was proposed that in this low-temperature phase, the interplay between a strong spin-orbital coupling and the transfer integral could realise a rare case of an intrinsically half-filled flat band dispersion with a stiff spin chirality [2].

In this talk, we will present our recent high pressures transport measurement on CsW_2O_6. With increasing pressure, we find that the low-temperature insulating phase is stabilised as the metal-to-insulator transition shifts to higher temperatures. We will discuss our results in the light of recent theoretical proposals.
[1] Y. Okamoto et al., Nat. Commun. 11 (2020)
[2] N. Nakai and C. Hotta, Nat. Commun. 13 (2022)

TT 9: Cold Atomic Gases and Superfluids

Time: Monday 18:00–19:15 Location: H23

TT 9.1 Mon 18:00 H23

Symmetry-protected Bose-Einstein condensation of interacting hardcore bosons — •Reja Wilke[1], Thomas Köhler[2], Felix Palm[1], and Sebastian Paeckel[1] — [1]Department of Physics, Arnold Sommerfeld Center for Theoretical Physics, University of Munich, Germany — [2]Department of Physics and Astronomy, Uppsala University, Sweden

We introduce a mechanism stabilizing a one-dimensional quantum many-body phase, characterized by a certain wave vector via the protection of an emergent $\mathbb{Z}_2$ symmetry. We illustrate this mechanism by constructing the solution of the full quantum many-body problem of hardcore bosons on a wheel geometry, which are known to form a Bose-Einstein condensate. The robustness of the condensate is shown numerically by adding nearest-neighbor interactions to the wheel Hamiltonian. We discuss further applications such as geometrically inducing finite-momentum condensates.

TT 9.2 Mon 18:15 H23

Quantum light-matter fluctuations in driven open cavity BEC systems — •Leon Mixa and Michael Thorwart — I. Institut für Theoretische Physik, Universität Hamburg

When an ultracold atom gas strongly interacts with a pumped cavity light field, effective retarded long-range interactions are induced. They give rise to non-classical states in the light sector, which do not necessarily require non-classical fluctuations in the matter sector. We study theoretically the quantum fluctuations in the light and the matter sectors in different driving regimes. In particular, the photon dissipation channel of the cavity allows for the direct nondestructive measurement of the fluctuations driving the phase transition known in this system. Light-induced density fluctuations drive a superradiant nonequilibrium Dicke quantum phase transition of the atom gas. The photon statistics in the presence of the strongly coupled, pumped atom gas is calculated within a Bogoliubov approach combined with analytic imaginary time path integrals including photon leakage of the cavity. Parameter regimes for squeezed cavity light are identified.

TT 9.3 Mon 18:30 H23

The free energy of the two-dimensional dilute Bose gas — •Andreas Deuchert[1], Simon Mayer[2], and Robert Seiringer[2] — [1]University of Zurich, Institute of Mathematics, Zurich, Switzerland — [2]Institute of Science and Technology Austria, Klosterneuburg, Austria

We prove bounds for the specific free energy of the two-dimensional Bose gas in the thermodynamic limit. We show that the free energy at density ϱ and inverse temperature β differs from the one of the non-interacting system by the correction term $4\pi\varrho^2|\ln(a^2\varrho)|^{-1}(2-[1-\beta_c/\beta]_+^2)$. Here a is the scattering length of the interaction potential, $[x]_+ = \max\{0,x\}$ and β_c is the inverse Berezinskii–Kosterlitz–Thouless critical temperature for superfluidity. The result is valid in the dilute limit $a^2\varrho \ll 1$ and if $\beta\varrho \gtrsim 1$.

TT 9.4 Mon 18:45 H23

Chaos in the three-site Bose-Hubbard model - classical vs quantum — •Goran Nakerst[1] and Masudul Haque[1,2] — [1]Institut für Theoretische Physik, Technische Universität Dresden, Dresden, Germany — [2]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

We consider a quantum many-body system - the Bose-Hubbard system on three sites - which has a classical limit, and which is neither strongly chaotic nor integrable but rather shows a mixture of the two types of behavior. We compare quantum measures of chaos (eigenvalue statistics and eigenvector structure) in the quantum system, with classical measures of chaos (Lyapunov exponents) in the corresponding classical system. As a function of energy and interaction strength, we demonstrate a strong overall correspondence between the two cases. In contrast to both strongly chaotic and integrable systems, the largest Lyapunov exponent is shown to be a multi-valued function of energy.

TT 9.5 Mon 19:00 H23

Out-of-equilibrium dynamics of bosons on a 2D Hub-

bard lattice — •Ulli Pohl, Sayak Ray, and Johann Kroha — Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn, Nußallee 12, 53115 Bonn, Germany

We study the collective excitations of bosons in two-dimensional optical Hubbard lattices, described by the Bose-Hubbard model, using the cluster mean field theory at zero temperature. The method has been shown to be very powerful to determine the phase boundaries both at zero and finite temperatures [1]. From the low-lying excitations, we identify the presence of the Higgs and the Goldstone modes of the superfluid, as well as the particle- and hole-like excitations in the Mott insulator phase and calculate their dispersion relations. The effective mass of the quasiparticles and -holes vanish at the tip of the Mott lobe where the Higgs energy gap also vanishes. Finally, we present the real time dynamics of the collective excitations, particularly, the Higgs mode. Our findings, particularly the dynamics of excitations support the previous mean-field-like calculations and can be relevant for cold-atom experiments.

[1] U. Pohl, S. Ray, J. Kroha arXiv:2106.14860

TT 10: Focus Session: Superconductivity in 2d-Materials and their Heterostructures

Two-dimensional crystals have become important throughout condensed matter physics. Only a few of them are intrinsic superconductors, most of these containing heavy elements. Hence, Cooper pairing is strongly affected by spin-orbit interactions that lead to exotic features like Ising pairing and mixed singlet-triplet correlations. The unconventional pairing offers novel degrees of freedom and integrates superconductivity with topological and even higher-order topological edge and hinge states. Moreover, proximity induced superconductivity displays characteristic features owing to the ballistic character and the Dirac dispersion relation of today's high-quality hexagonal boron nitride/graphene heterostructures. This makes graphene-based heterostructures an interesting platform for Andreev billiards and similar systems.

Organizers: Christoph Stampfer, RWTH Aachen University and Christoph Strunk, University of Regensburg

Time: Tuesday 9:30–13:15 Location: H3

Invited Talk TT 10.1 Tue 9:30 H3

Two-fold symmetric superconductivity in few-layer $NbSe_2$ — •Vlad Pribiag — University of Minnesota, USA

Few-layer samples of transition metal dichalcogenides (TMDs) feature a wide array of properties such as layer-dependent inversion symmetry, valley-contrasted Berry curvatures, and strong spin-orbit coupling (SOC). Among the superconducting TMDs, $NbSe_2$ is profoundly affected by Ising SOC. Ising SOC not only helps stabilize the superconducting state against large in-plane magnetic fields, but in conjunction with other forms of SOC, it could also give rise to exotic superconducting states such as nodal topological superconductivity. This talk will discuss recent transport measurements of few-layer $NbSe_2$, and $NbSe_2/CrBr_3$ junctions, studied under in-plane external magnetic fields. Surprisingly, although the crystal lattice has a three-fold symmetry, the magneto-resistance and critical field show a two-fold anisotropy, which is absent in the normal state. We will discuss these results in the context of a competition between the conventional s-wave pairing instability characteristic of the bulk and a competing d- or p-wave instability that emerges in the few-layer limit. These results [1] suggest an unconventional character for superconducting pairing in $NbSe_2$ and open the possibility for further discoveries, such as nontrivial topologies, in few-layer TMDs.

[1] A. Hamill et al., Nat. Phys. 17, 949 (2021)

Invited Talk TT 10.2 Tue 10:00 H3

Spin-orbit coupling and triplet pairing in mesoscopic superconductors — •marco aprili[1], marko kuzmanovic[1], tom dvir[2], david leboeuf[3], stefan ilic[4], menashe haim[2], maxim khodas[2], julia meyer[4], hadar steinberg[2], and charis quay[1] — [1]Laboratoire de Physique des Solides, Bâtiment 510, Université Paris-Saclay 91405 Orsay, France — [2]Racah Institute of Physics, Hebrew University of Jerusalem, Givat Ram, Jerusalem 91904 Israel — [3]Laboratoire National des Champs Magnétiques Intenses, CNRS, Grenoble, France — [4]Université Grenoble Alpes, CEA, Grenoble INP, 38000 Grenoble, France

The spin-orbit coupling which is present in in 2D materials because of inversion breaking symmetry allows a triplet component of the superconducting order parameter to appear.

In presence of an external magnetic field acting on the spin degree of freedom of the electron pairs forming the condensate, this spin-orbit coupling originates a spontaneous supercurrent and hence a phase difference. In a monolayer of a superconducting transition-metal-dichancogenides such as NbSe2, the lack of in-plane crystal inversion symmetry, results instead in a large valley Zeeman splitting which pins the spins out-of-plane and protects in fact superconductivity. Adding an external magnetic field results in a mix singlet-triplet superconducting state where the two order parameters are linearly coupled by the field. The triplet is an equal spin paring state. In this talk I'll present a series of quantum transport and tunneling spectroscopy experiments in mesoscopic superconductors that address these issues.

Invited Talk TT 10.3 Tue 10:30 H3

Supercurrent diode effect in few-layer $NbSe_2$ — Lorenz Bauriedl[1], Christian Bäuml[1], Lorenz Fuchs[1], Christian Baumgartner[1], Nicolas Paulik[1], Jonas M. Bauer[1], Kai-Qiang Lin[1], John M. Lupton[1], Takashi Taniguchi[2], Kenji Watanabe[2], Christoph Strunk[1], and •Nicola Paradiso[1] — [1]Institut für Experimentelle und Angewandte Physik, University of Regensburg, Regensburg, Germany — [2]International Center for Materials Nanoarchitectonics, National Institute for Materials Science, Tsukuba, Japan

Current rectifiers are devices which display a largely different resistance for the two opposite bias polarities. Recent seminal works on Rashba superconductors have demonstrated that a simultaneous breaking of time- and inversion-symmetry leads to supercurrent rectification, where for one direction the resistance is strictly zero. Owing to the symmetry of the Rashba spin-orbit interaction, the effect is controlled by the in-plane field. In this work, we report on a supercurrent diode effect in few layer-thick $NbSe_2$ constrictions. As predicted by theory for valley Zeeman spin-orbit interaction (SOI), the observed supercurrent rectification is controlled by the *out-of-plane* field B_z. Remarkably, the in-plane field does play a role: it determines a preferred direction for the out-of-plane field, making the rectification effect asymmetric in B_z. Such asymmetry is in contrast to theory expectations for pure valley Zeeman spin-orbit. Instead, it points toward the presence of an additional Rashba SOI component in $NbSe_2$.

15 min. break

Invited Talk TT 10.4 Tue 11:15 H3

Superconducting devices in magic-angle twisted bilayer graphene — •Folkert de Vries[1], Elias Portoles[1], Giulia Zheng[1], Shuichi Iwakiri[1], Kenji Watanabe[2], Takashi Taniguchi[2], Thomas Ihn[1], and Klaus Ensslin[1] — [1]Laboratory for Solid State Physics, ETH Zurich, Otto-Stern-Weg 1,Zurich, Switzerland — [2]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

In situ electrostatic control of two-dimensional superconductivity is commonly limited due to large charge carrier densities, and gate-defined superconducting devices are therefore rare. Magic-angle twisted bilayer graphene (MATBG) has recently emerged as a versatile platform that combines metallic, superconducting, magnetic and insulating phases in a single crystal. Here we use multilayer gate technology and physical etching to create devices based on distinct phases in adjustable regions of MATBG. We electrostatically define the superconducting and insulating regions of a Josephson junction and observe tunable d.c. and a.c. Josephson effects. Futhermore, we form a ring shaped geometry with two Josephson junctions known as a superconducting quantum interference device. We observe the expected coherent oscillations of the supercurrent and extract characteristics such as the current phase relation and inductance. These works are an initial steps towards devices where gate-defined correlated states are connected in single-crystal nanostructures. We envision applications in superconducting electronics and quantum information technology.

Invited Talk TT 10.5 Tue 11:45 H3

Minigap and Andreev bound states in ballistic graphene — •Luca Banszerus[1,2], Florian Libisch[3], Andrea Ceruti[1], Stefan Blien[4], Kenji Watanabe[5], Takashi Taniguchi[5], Andreas Hüttel[4], Bernd Beschoten[1], Fabian Hassler[1], and Christoph Stampfer[1] — [1]RWTH Aachen University, Germany — [2]Forschungszentrum Jülich, Germany — [3]TU Vienna, Austria — [4]University of Regensburg, Germany — [5]National Institute for Materials Science, Japan

A finite-size normal conductor, proximity-coupled to a superconductor has been predicted to exhibit a so-called minigap, in which quasiparticle excitations are prohibited. In this talk, we demonstrate the direct observation of such a minigap through transport measurements on partially gated ballistic graphene, coupled to superconducting MoRe contacts [1]. The minigap is probed by finite bias spectroscopy through a weakly coupled junction in the graphene region and its value is given by the dimensions of the device. Besides the minigap, a distinct peak in the differential resistance is observed, which we attribute to weakly coupled Andreev bound states (ABS) located near the superconductor-graphene interface. For weak magnetic fields, the phase accumulated in the normal-conducting region shifts the ABS in quantitative agreement with predictions from tight-binding calculations based on the Bogolioubov-de Gennes equation as well as with an analytical semiclassical model.

[1] arXiv:2011.11471

TT 10.6 Tue 12:15 H3

Competition of Density Waves and Superconductivity in Twisted Tungsten Diselenide — •Lennart Klebl[1], Ammon Fischer[1], Laura Classen[2], Michael M. Scherer[3], and Dante M. Kennes[1,4] — [1]Institut für Theorie der Statistischen Physik, RWTH Aachen University and JARA-Fundamentals of Future Information Technology, D-52056 Aachen, Germany — [2]Max Planck Institute for Solid State Research, D-70569 Stuttgart, Germany — [3]Institut für Theoretische Physik III, Ruhr-Universität Bochum, D-44801 Bochum, Germany — [4]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, D-22761 Hamburg, Germany

Evidence for correlated insulating and superconducting phases around regions of high density of states was reported in the strongly spin-orbit coupled van-der Waals material twisted tungsten diselenide (tWSe_2). We investigate their origin and interplay by using a functional renormalization group approach that allows to describe superconducting and spin/charge instabilities in an unbiased way. We map out the phase diagram as function of filling and perpendicular electric field, and find that the moiré Hubbard model for tWSe_2 features mixed-parity superconducting order parameters with s/f-wave and topological d/p-wave symmetry next to (incommensurate) density wave states. Our work systematically characterizes competing interaction-driven phases in tWSe_2 beyond mean-field approximations and provides guidance for experimental measurements by outlining the fingerprint of correlated states in interacting susceptibilities.

TT 10.7 Tue 12:30 H3

Tuning lower dimensional superconductivity with hybridization at a superconducting-semiconducting interface — •M. Simonato[1], A. Kamlapure[1], E. Sierda[1], M. Steinbrecher[1], U. Kamber[1], E. J. Knol[1], P. Krogstrop[2,3], M.I. Katsnelson[1], A.A. Khajetoorians[1], and M. Rösner[1] — [1]Radboud University, Institute for Molecules and Materials, Nijmegen, The Netherlands — [2]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark — [3]Microsoft Quantum Materials Lab Copenhagen, Lyngby, Denmark

We demonstrate that the hybrid electronic structure derived at the interface between semiconducting black phosphorus and atomically thin films of lead can drastically modify the superconducting properties of the thin metallic film. Using ultra-low temperature scanning tunneling microscopy and spectroscopy, we observe a strongly anisotropic renormalization of the superconducting gap. To study the effect of hybridization, we develop a hybrid two-band model as an extension to conventional BCS theory in the Nambu-Gorkov formalism. In this model, we obtain analytical expressions for the effective gap and link the hybridization-driven renormalization to a weighting of the superconducting order parameter that quantitatively reproduces the measured spectra. These results illustrate the effect of interfacial hybridization at superconductor-semiconductor heterostructures, and pathways for engineering quantum technologies based on gate-tunable superconducting electronics.

TT 10.8 Tue 12:45 H3

Ab inito study of the van der Waals Superconductor $NbSe_2$ — •Mohammad Hemmati, Philipp Rüssmann, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany

Transition metal dichalcogenides (TMDCs) are a very versatile material class in which a plethora of physical phenomena can be realized. This ranges from the topological electronic structure in Weyl and Dirac semimetals to magnetic and even superconducting systems that can furthermore be combined due to the intrinsic van der Waals stacking in these materials. The TMDC $NbSe_2$ is an example of a layered superconducting material which shows, for instance, the unconventional Ising superconductivity that is particularly robust against magnetic fields [1]. We study bulk and single-layer $NbSe_2$ on the basis of first-principles calculations within the Korringa-Kohn-Rostoker Green function method which allows combining the accurate description of the electronic structure on the basis of density functional theory with a description of the superconductivity via the Bogoliubov-de Gennes formalism [2,3].

This work was funded 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.

[1] D. Wickramaratne *et al.*, Phys. Rev. X **10**, 041003 (2020)
[2] https://jukkr.fz-juelich.de
[3] P. Rüßmann, S. Blügel, arXiv:2110.01713 (2021)

TT 10.9 Tue 13:00 H3

Emergence of unconventional proximity effect in $Cr_1/3NbS_2/NbS_2$ heterostructures — •Alfredo Spuri, Roman Hartmann, Elke Scheer, and Angelo Di Bernardo — University of Konstanz

The helimagnetic metal $Cr_1/3NbS_2$ has been reported to host soliton excitations based on magnetransport measurements which have been performed on flakes of this material down to the 2D limit. Investigating the proximity effect between 2D flakes of such a magnetic material and conventional 2D superconductors could lead to the discovery of unconventional spin-triplet superconducting states, with possible applications for superconducting spintronics and quantum computing. Based on these motivations, we have fabricated 2D $Cr_1/3NbS_2/NbSe_2$ and $Cr_1/3NbS_2/NbS_2$ bilayers and investigated their low temperature magnetotransport and spectroscopic properties. In addition, we have also realized $/NbSe_2/Cr_1/3NbS_2/NbSe_2$ Josephson junctions and performed measurements on them. The results obtained give indication for the emergence of an unconventional proximity effect, possibly due to the emergence of spin-triplet pairing correlations.

TT 11: Topology: Quantum Hall Systems

Time: Tuesday 9:30–12:30 Location: H10

TT 11.1 Tue 9:30 H10

Quantum Hall effect induced by chiral Landau levels in topological semimetal films — •Duy-Hoang-Minh Nguyen[1], Koji Kobayashi[2], Jan-Erik Reinhard Wichmann[3], and Kentaro Nomura[2] — [1]Donostia International Physics Center, Donostia-San Sebastian, Spain — [2]Department of Physics, Kyushu University, Fukuoka, Japan — [3]Institute for Materials Research, Tohoku University, Sendai, Japan

Motivated by recent transport experiments, we theoretically study the quantum Hall effect in topological semimetal films. Owing to the confinement effect, the bulk subbands originating from the chiral Landau levels establish energy gaps that have quantized Hall conductance and can be observed in relatively thick films. We find that the quantum Hall state is strongly anisotropic for different confinement directions not only due to the presence of the surface states but also because of the bulk chiral Landau levels. As a result, we re-examine the quantum Hall effect from the surface Fermi arcs and chiral modes in Weyl semimetals and give a more general view into this problem. Also, we find that when a topological Dirac semimetal is confined in its rotational symmetry axis, it hosts both quantum Hall and quantum spin Hall states, in which the helical edge states are protected by the conservation of the spin-z component.

TT 11.2 Tue 9:45 H10

Quantum Hall critical phase at topological insulator surfaces — •Johannes Dieplinger[1], Mateo Moreno-Gonzalez[2], Soumya Bera[3], Martin Puschmann[1], Matthew Foster[4], Ferdinand Evers[1], and Alexander Altland[2] — [1]University of Regensburg, Regensburg, Germany — [2]Universiy of Cologne, Cologne, Germany — [3]IIT Bombay, Mumbai, India — [4]Rice University, Houston, Texas, USA

We show that an AIII three-dimensional topological insulator, when tuned away from the critical point at zero energy, realizes a finite class A critical phase on its surface, i.e. a continuum of quantum Hall critical states, instead of an naively expected quantum Hall insulator. Criticality is characterized numerically via an analysis of the multifractal exponents of the wave functions at the surface of the three dimensional bulk.

This numerical work supports a recently proposed first principle theory explaining the existence of the quantum Hall critical phase. Open questions remain concerning the nature of disordered surface states with higher topological index.

TT 11.3 Tue 10:00 H10

Universal properties of boundary and interface charges in multichannel models of one-dimensional insulators — •Kiryl Piasotski[1], Niklas Muller[1], Dante Kennes[1,2], Herbert Schoeller[1], and Mikhail Pletyukhov[1] — [1]Institut fur Theorie der Statistischen Physik, RWTH Aachen, 52056 Aachen, Germany — [2]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, 22761 Hamburg, Germany

Generalizing our previous results on a one-dimensional single-channel continuum [1] and multichannel tight-binding [2] models, we present novel topological invariants to characterize boundary and interface charges in systems described by one-dimensional Schrödinger operators with periodic non-Abelian vector and scalar potentials. In particular, we prove that the change in boundary charge upon the continuous shift of the system towards the boundary by the distance $x_\varphi \in [0, L]$ (L-period) is given by the sum of the linear function of x_φ and an integer-valued topological index $I(x_\varphi)$ - the boundary invariant, and provide two equivalent representations of $I(x_\varphi)$. In addition, we study translationally invariant systems interrupted by a localized impurity, we show that an excess charge on the impurity is a quantized integer quantity given by a winding number expression.

[1] Phys. Rev. B **104**, 155409 (2021)
[2] Phys. Rev. B **104**, 125447 (2021)

TT 11.4 Tue 10:15 H10

antiferromagnetic chern insulator in a centrosymmetric system — •morad ebrahimkhas[1], mohsen hafez-torbati[2], and walter hofstetter[1] — [1]Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt/Main, Germany — [2]Lehrstuhl für Theoretische Physik I, Technische Universität Dortmund, Otto-Hahn-Straße 4, 44221 Dortmund, Germany

An antiferromagnetic Chern insulator (AFCI) can exist if the effect of the time-reversal transformation on the AF state cannot be compensated by a space group operation. Such a state has recently been reported in a noncentrosymmetric Kane-Mele-Hubbard model. We investigate the possible emergence of this phase in a centrosymmetric system. We consider a minimal extension of the time-reversal invariant Harper-Hofstadter- Hatsugai model. The next-nearest-neighbor hopping opens a gap at half-filling and allows for the realization of a quantum spin Hall insulator. We add to the system a staggered potential Δ and the Hubbard interaction U favoring a normal insulator and a Mott insulator, respectively. We map out the phase diagram of the model in the U-Δ plane and show that an AFCI with the Chern number C = 1 appears for (U∼2Δ) ≫ t. We find that for a fixed Δ upon increasing U a spin-flop transition from the C = 1 z-AFCI to a topologically trivial xy-AF phase takes place. Our findings can be used as a guideline in future investigations searching for an AFCI in optical lattices.

TT 11.5 Tue 10:30 H10

Supercurrent-enabled Andreev reflection in a chiral quantum Hall edge state — Andreas Bock Michelsen[1,2], Patrik Recher[3], Bernd Braunecker[1], and •Thomas L. Schmidt[2] — [1]University of St Andrews, UK — [2]University of Luxembourg, Luxembourg — [3]Technische Universität Braunschweig, Germany

A chiral quantum Hall (QH) edge state placed in proximity to an s-wave superconductor experiences induced superconducting correlations. Recent experiments have observed the effect of proximity-coupling in QH edge states through signatures of the mediating process of Andreev reflection. We present the microscopic theory behind this effect by modeling the system with a many-body Hamiltonian, consisting of an s-wave superconductor, subject to spin-orbit coupling and a magnetic field, which is coupled by electron tunneling to a QH edge state. By integrating out the superconductor we obtain an effective pairing Hamiltonian in the QH edge state. We clarify the qualitative appearance of nonlocal superconducting correlations in a chiral edge state and analytically predict the suppression of electron-hole conversion at low energies (Pauli blocking) and negative resistance as experimental signatures of Andreev reflection in this setup. In particular, we show how two surface phenomena of the superconductor, namely Rashba spin-orbit coupling and a supercurrent due to the Meissner effect, are essential for the Andreev reflection. Our work provides a promising pathway to the realization of Majorana zero-modes and their parafermionic generalizations.

15 min. break

TT 11.6 Tue 11:00 H10

Synthetic gravitational horizons in low-dimensional quantum matter — •Corentin Morice[1], Ali G. Moghaddam[2,3], Dmitry Chernyavsky[2], Jasper van Wezel[1], and Jeroen van den Brink[2,4] — [1]Institute for Theoretical Physics and Delta Institute for Theoretical Physics, University of Amsterdam, 1090 GL Amsterdam, The Netherlands — [2]Institute for Theoretical Solid State Physics, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [3]Department of Physics, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan 45137-66731, Iran — [4]Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universitt Dresden, 01069 Dresden, German

We propose a class of lattice models realizable in a wide range of setups whose low-energy dynamics exactly reduces to Dirac fields subjected to (1+1)-dimensional gravitational backgrounds, including (anti-)de Sitter spacetime. Wave-packets propagating on the lattice exhibit an eternal slowdown for power-law position-dependent hopping integrals $t(x) \propto x^\gamma$ when $\gamma \geq 1$, signalling the formation of black hole event horizons. For $\gamma < 1$ instead the wave-packets behave radically different and bounce off the horizon. We show that the eternal slowdown relates to a zero-energy spectral singularity of the lattice model and that the semiclassical wave packets trajectories coincide with the geodesics on (1+1)D dilaton gravity, paving the way for new and experimentally feasible routes to mimic black hole horizons and realize (1+1)D spacetimes as they appear in certain gravity theories.

TT 11.7 Tue 11:15 H10

Adiabatic preparation of fractional quantum Hall phases from the thin torus limit — •Benjamin Michen[1], Cécile Repellin[2], and Jan Carl Budich[1] — [1]Institute of Theoretical Physics, Technische Universität Dresden — [2]Univ. Grenoble-Alpes, CNRS, LPMMC, 38000 Grenoble, France

We explore as to what extent reversing the thin torus (TT) limit enables the adiabatic preparation of fractional quantum Hall (FQH) states in quantum simulators. As a novel approach, the TT limit is taken by increasing the hopping amplitude in one direction in order to make the system effectively one-dimensional.

The regime of strongly anisotropic coupling features the expected charge density wave (CDW) ground state. The CDW state can be adiabatically connected to the FQH state by tuning the coupling back to the isotropic regime without closing the many-body excitation gap along the way. This may provide an experimental path to the adiabatic preparation of FQH states from topologically trivial CDW states.

We find that the many-body excitation gap in the TT limit decreases with system size for fully discrete models, which limits the adiabatic preparation. However, there appears to be no such restriction in a semicontinuous setup of coupled wires. In that sense, the proposed protocol could be experimentally relevant for arbitrary system sizes.

TT 11.8 Tue 11:30 H10

Non-Hermitian topological signatures in a quantum Hall system — •Raghav Chaturvedi[1], Kyrylo Ochkan[1], Viktor Könye[1], Ewelina Hankiewicz[2], Jeroen van den Brink[1], Joseph Dufouleur[1], and Cosma Fulga[1] — [1]IFW Dresden, Deutschland — [2]Julius Maximilian University of Würzburg

Reflection matrices describing waves reflected from the boundaries of insulators exhibit non-Hermitian topological signatures. Drawing from this, we propose to realize non-Hermitian topology in the quantum regime of a two dimensional condensed-matter system. Our work is based on the insight that, in the limit of maximal non-reciprocity, the Hamiltonian for the simplest topological non-Hermitian system – the Hatano-Nelson chain – effectively describes a one-dimensional, unidirectionally propagating mode. This is analogous to the unidirectional boundary mode of a fully Hermitian topological insulator: the quantum Hall system. We show that the multi-terminal conductance matrix of this system exhibits a topologically protected non-Hermitian skin effect. Moreover, we show that the topological invariant characterizing these features is more robust than the Chern number, as it remains well-quantized even across quantum Hall plateau transitions. Our work shows that the transport properties of Chern insulators may exhibit signatures of non-Hermitian topology, and this paves the way for the first experimental observation of non-Hermitian topology in a quantum condensed-matter system, which will be presented by another author.

TT 11.9 Tue 11:45 H10

Observation of non-Hermitian topology in a multi-terminal quantum Hall device — •Kyrylo Ochkan[1], Raghav Chaturvedi[1], Viktor Könye[1], Ewelina Hankiewicz[2], Jeroen van den Brink[1], Joseph Dufouleur[1], and Cosma Fulga[1] — [1]IFW Dresden, Deutschland — [2]Julius-Maximilians-Universität Würzburg, Deutschland

One of the simplest examples of non-Hermitian topology is encountered in the Hatano-Nelson (HN) model, a one-dimensional chain where the hopping in one direction is larger than in the opposite direction. We present here the first experimental observation of non-Hermitian topology in a quantum condensed-matter system. The measurements are done in a multi-terminal quantum Hall device etched in a high mobility GaAs/AlGaAs two-dimensional electron gas ring. The conductance matrix that connects the currents flowing from the active contacts to the ground with the voltage of the active contacts is topologically equivalent to the HN Hamiltonian.

In our device, we directly measure and evidence the non-Hermitian skin effect. We also compute for our experimental device two topological invariants that are found to be more robust than the Chern number. We finally use the unique properties of our system and continuously tune the system configuration between open and periodic boundary conditions.

We focus here on the experimental results, whereas the theoretical aspects of the non-Hermitian skin effect and the topological invariants will be discussed in another presentation.

TT 11.10 Tue 12:00 H10

Emergent non-Hermitian topology and boundary sensitivity in interacting Su-Schrieffer-Heeger chains — •Tommaso Micallo, Carl Lehmann, and Jan Carl Budich — Institute of Theoretical Physics, Technische Universität Dresden and Würzburg-Dresden Cluster of Excellence ct.qmat, 01062 Dresden, Germany

The exponential sensitivity of effective Non-Hermitian (NH) Hamiltonians with respect to boundary conditions has recently been predicted and observed in a broad range of settings. Here, we discuss as to what extent this remarkable phenomenon may occur in closed correlated fermionic systems that are governed by a Hermitian many-body Hamiltonian. There, an effectively NH quasiparticle description naturally arises in the Green's function formalism due to inter-particle scattering that represents a source of inherent dissipation. Using exact diagonalization, we analyze as a concrete platform extended Su-Schrieffer-Heeger (SSH) chains with interactions subject to varying boundary conditions.

TT 11.11 Tue 12:15 H10

Absent thermal equilibration on fractional quantum Hall edges over macroscopic scale — •Ron Melcer[1], Bivas Dutta[1], Christian Spanslatt[2,3,4], Jinhong Park[5], Alexander Mirlin[3,4], and Vladimir Umansky[1] — [1]Braun Center for Submicron Research, Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, 761001, Israel — [2]Department of Microtechnology and Nanoscience, Chalmers University of Technology, S-412 96, Göteborg, Sweden — [3]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021, Karlsruhe, Germany — [4]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, 76128, Karlsruhe, Germany — [5]Institute for Theoretical Physics, University of Cologne, Zülpicher Str. 77, 50937, Köln, Germany

Two-dimensional topological insulators, and in particular quantum Hall states, are characterized by an insulating bulk and a conducting edge. Fractional states may host both downstream (dictated by the magnetic field) and upstream propagating edge modes, which leads to complex transport behavior. Here, we combine two measurement techniques, local noise thermometry and thermal conductance, to study thermal properties of states with counter-propagating edge modes. We find that, while charge equilibration between counter-propagating edge modes is very fast, the equilibration of heat is extremely inefficient, leading to an almost ballistic heat transport over macroscopic distances. Moreover, we observe an emergent quantization of the heat conductance associated with a strong interaction fixed point of the edge modes.

TT 12: Correlated Electrons: Materials

Time: Tuesday 9:30–13:00 Location: H22

TT 12.1 Tue 9:30 H22

Low-dimensional magnetism in ordered perovskite and Ruddlesden-Popper variants — •Ryan Morrow, Anastasiia Smerechuk, Tamara Holub, Sabine Wurmehl, and Bernd Büchner — Leibniz Institute for Solid-State and Materials Research, IFW-Dresden, 01069 Dresden, Germany

Perovskites and their myriad of structural permutations have long been studied for their intriguing properties and interplay of degrees of freedom, both chemical and physical. While generally three dimensional in nature, perovskites can provide multiple means of access to low dimensional properties as well. In this talk, new results in three different directions pertaining to this concept will be presented. The first, most common approach, is the use of the Ruddlesden-Popper and similar phases, which separate perovskite-like layers with interlaced AO layers, rendering them primarily two dimensional. Several new cation-ordered iridate and rhodate Ruddlesden-Popper phases will be presented. The second approach is that of orbital order using Cu^{2+} in the double perovskite structure to yield in-plane only square lattice like magnetic interactions (e.g. Ba_2CuWO_6). New compounds produced by substitution series and high pressure methods will be shown. The third is that of vacancy ordering. By ordering of vacancies in combination with cation ordering, hexagonal perovskite phases can be reduced to well separated triangular two dimensional magnets with variable spin sizes and frustration. Again, new compounds will be shown. In all three directions, primarily crystallographic and magnetometry data on these new inorganic transition metal oxides will be presented.

TT 12.2 Tue 9:45 H22

Strain mediated phase transitions in $SrCrO_3$ — •Alberto Carta and Claude Ederer — Materials Theory, ETH Zurich, Switzerland

$SrCrO_3$ is a complex perovskite oxides that can exhibit a plethora of interesting and technologically promising characteristics. However, available experimental reports still disagree on whether the material is metallic or semiconducting, or whether it is paramagnetic or antiferromagnetic. In a recent pre-print, Bertino et al. also reported a transition from conducting to insulating behavior for thin films of $SrCrO_3$ grown at different levels of epitaxial strain [1]. In our work, we use density functional theory (DFT) and DFT+U to establish the basic properties of $SrCrO_3$. Our calculations clearly suggest a metallic C-type antiferromagnetic ground state, consistent with previous DFT studies[2]. Furthermore, we show that the electronic and magnetic properties of $SrCrO_3$ are strongly influenced by epitaxial strain, and that the system can develop orbital order coupled to a Jahn-Teller structural distortion under tensile strain. We explore the regime where this distortion is possible and propose a mechanism for the transition to the insulating state that is consistent with the observations of [1].

[1] G. Bertino, H.C. Hsing, A. Gura, X. Chen, T. Sauyet, M. Liu, C.Y. Nam, M. Dawber, arXiv: 2104.02738 (2021)
[2] K.W. Lee, W. E. Pickett, Phys. Rev. B 80, 1 (2009)

TT 12.3 Tue 10:00 H22

Thermodynamic Signatures of the Soliton Lattice in Single-Crystal $TbFeO_3$ — •Alexander Engelhardt[1], Johanna Jochum[2], Andreas Bauer[1], Andreas Erb[3], Astrid Schneidewind[4], and Christian Pfleiderer[1] — [1]TU München, Garching, Germany — [2]Heinz Maier-Leibnitz Zentrum (MLZ), TU München, Garching, Germany — [3]Walther-Meißner-Institut, Garching, Germany — [4]Forschungszentrum Jülich GmbH, Jülich Center for Neutron Sciences at MLZ, Garching, Germany

The properties of the orthorhombic perovskite $TbFeO_3$ originate from the interplay of a Tb and Fe magnetic sublattices, resulting in a complex magnetic phase diagram. Perhaps most remarkable, at low temperatures, a complex and anharmonic magnetic structure, a so-called magnetic soliton lattice, was identified by means of neutron scattering under magnetic fields up to 4 T [1]. Here, we report the single-crystal growth of $TbFeO_3$ using a combination of a solid-state reactions and optical float-zoning. Measurements of the magnetic ac susceptibility and the specific heat are characteristic of strong easy-plane magnetic anisotropy with two prominent magnetic phase transitions in zero magnetic field at 8 K and 3 K, consistent with the literature. By combining transverse-field ac susceptibility measurements with neutron scattering, we have determined the magnetic phase diagram. When a magnetic field is applied along the hard magnetic c axis, the soliton lattice may be traced up to 12 T, the highest field studied.

[1] S. Artyukhin et al., Nat. Mater. 11, 694 (2012)

TT 12.4 Tue 10:15 H22

Lattice dynamic of $LiReO_3$ across the continuous ferroelectric-like structural transition — •Ksenia Denisova[1], Peter Lemmens[1], Kantaro Murayama[2], Xiangyu Gu[2], Hiroshi Takatsu[2], Cedric Tassel[2], and Hiroshi Kageyama[2] — [1]IPKM, TU BS, Braunschweig, Germany — [2]Kyoto University, Kyoto, Japan

The observation of a ferroelectric instability in metallic $LiOsO_3$ [1] with strongly correlated electrons [2] has fueled an intense discussion on the origin of polar metallicity. A comparative Raman study [3] of the isostructural compound $LiReO_3$ reveals that the enlarged lattice parameters leads to softer Li vibrations and enhances fluctuations in the system. The phonon anomalies point to the phase transition at T=175 K with a crossover regime to temperatures as low as 140 K. The hysteresis in the temperature evolution of ReO_6 related modes as opposed to an abrupt softening of Li vibrations in the ferroelectric phase speaks in favour of a decoupling of polar degrees of freedom and itinerant electrons.

Work supported by the DFG EXC-2123-390837967 Quantum-Frontiers, DFG Le967/16-1, and DFG-RTG 1952/1.

[1] Y. Shi et al., Nat. Mater. 12, 1024 (2013)
[2] J.S. Zhou et al., PRB 104, 115130 (2021)
[3] F. Jin et al., PNAS 116, 20322 (2019)

TT 12.5 Tue 10:30 H22

Magnetic anisotropy, magnetoelastic coupling and the phase diagram of $Ni_{0.25}Mn_{0.75}TiO_3$ — •Ahmed Elghandour, Lukas Gries, Lennart Singer, Kaustav Dey, and Rüdiger Klingeler — Kirchhoff Institute for Physics, Heidelberg University, Heidelberg, Germany

Thermodynamic studies on high-quality single crystals of $Ni_{0.25}Mn_{0.75}TiO_3$ have been used to investigate magneto-structural coupling and to construct the magnetic phase diagram. Clear anomalies in the thermal expansion at the spin ordering and spin reorientation temperatures, T_N and T_R, evidence pronounced magneto-elastic effects. Notably, magnetic entropy is released mainly above T_N implying considerable short range magnetic order up to about $4T_N$. This is associated with a large regime of negative thermal expansion of the c axis. Both T_N and T_R exhibit the same sign of uniaxial pressure dependence which is positive (negative) for pressure applied along the b (c) axis. In addition, while our data indicate a glassy behaviour below $T^* \approx 3.7$ K, a significant amount of Ni^{2+} moments seems neither involved in long-range order not in the glassy state.

TT 12.6 Tue 10:45 H22

NMR investigations of a quasi-two-dimensional Heisenberg antiferromagnet 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 $[Cu(pz)_2(2\text{-HOpy})_2](PF_6)_2$ (CuPOF) 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 a commensurate antiferromagnetic (AF) quasistatic long-range order (LRO), with a preceding crossover from isotropic Heisenberg to anisotropic XY behavior. 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 ^1H and ^{31}P spectroscopy and relaxometry, revealing a monotonic change of T_N with increasing pressure. The commensurate AF LRO below T_N 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 12.7 Tue 11:00 H22

Electronic structure of $CeTAl_3$ (T=Ag, Au, Cu, Pd, Pt) studied with density functional theory — •André Deyerling[1], Andreas Bauer[1], Christian Franz[2], Marc A. Wilde[1], and Christian Pfleiderer[1] — [1]Physics Department, Technical University Munich, Garching, Germany — [2]Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ), Garching, Germany

The $CeTAl_3$ family (T=Ag, Au, Cu, Pd, Pt) is prototypical of strongly correlated electron systems with a large variety of different magnetic ordering phenomena [1,2,3,4], such as ferromagnetism in $CeAgAl_3$ and incommensurate antiferromagnetism in $CeAuAl_3$. Further, in $CeAuAl_3$ [5] and $CeCuAl_3$ [6] magnetoelastic hybrid excitations between crystal electric fields and phonons have been observed. The electronic structure, and in particular the role of the Ce–4f electron, is key for understanding the mechanism driving these phenomena. We report electronic structure calculations for selected members of the $CeTAl_3$ family, where the Ce–4f electrons are described either as being itinerant or localized using DFT or DFT+U, respectively. The results of our calculations treating the 4f electrons as localized are in good agreement with the experimental data available.

[1] C. Franz et al., J. Alloy. Comp. 668, 978 (2016)
[2] D.T. Adroja et al., Phys. Rev. B 91, 134425 (2015)
[3] M. Klipcera et al., Phys. Rev. B 91, 224419 (2015)
[4] M. Stekiel et al., arXiv:2106.08194 (2021)
[5] P. Čermák et al., Proc. Natl. Acad. Sci. 116, 6695 (2019)
[6] D.T Adroja et al., Phys. Rev. Lett. 108, 216402 (2012)

15 min. break

TT 12.8 Tue 11:30 H22

Charge-carrier properties near the bandwidth-controlled Mott transition in layered organic conductors probed by magnetic quantum oscillations — •Mark V. Kartsovnik[1], Sebastian Oberbauer[1,2], Shamil Erkenov[1,2], Werner Biberacher[1], and Natalia D. Kushch[1] — [1]Walther-Meißner-Institut, Garching, Germany — [2]Technische Universität München, Garching, Germany

Despite the great amount of work devoted to the Mott metal-insulator transition (MIT), some key theoretical predictions in this field are still awaiting experimental verification. In particular, there is no clarity about the exact behavior of the quasiparticle mass renormalized by many-body interactions, or about the pseudogap formation in the metallic ground state close to the bandwidth-controlled first-order MIT. Here we address these issues by employing organic κ-type salts as exemplary quasi-2D Mott systems and gaining direct access to their charge carrier properties via magnetic quantum oscillations. We trace the evolution of the effective cyclotron mass as the conduction bandwidth is tuned very close to the MIT by means of precisely controlled external pressure. We find that the sensitivity of the mass renormalization to subtle changes of the bandwidth strongly exceeds the theoretical predictions and is even further enhanced upon entering the transition region where the metallic and insulating phases coexist. On the other hand, even at this very edge of stability of the metallic ground state its Fermi surface remains fully coherent.

TT 12.9 Tue 11:45 H22

Anisotropic quasiparticle life times and magnetotransport in the doped Hubbard model — •Niklas Witt[1], Erik van Loon[2], Sergey Brener[1], Mikhail Katsnelson[3], Alexander Lichtenstein[1], and Tim Wehling[1] — [1]University of Hamburg, Hamburg, Germany — [2]Lund University, Lund, Sweden — [3]Radboud University, Nijmegen, The Netherlands

The strange metal phase of high-temperature superconducting copper oxide (cuprate) materials exhibits several unconventional transport properties like T-linear resistivity that do not conform to a conventional Fermi liquid description. The crossover to a normal metal for large dopings and the origin of the anomalous electronic properties remain unsolved problems.

Recent transport measurements [1,2] suggest that two different charge sectors exist, one with coherent quasiparticle charge carriers and the other with incoherent non-quasiparticle excitations. Only the former contributes to transport, leading to a drop of the Hall carrier density for small doping. To examine this hypothesis, we study the hole-doped Hubbard model using complementary many-body methods from the weak- and strong-coupling limit. We demonstrate that a dichotomy of the scattering rates between charge carriers from different momentum regions emerges which can lead to the reduction of the Hall carrier density already in the framework of semiclassical Boltzmann theory.

[1] M. Culo et al., SciPost Physics 11 (2021)
[2] J. Ayres et al., Nature 595, 661 (2021)

TT 12.10 Tue 12:00 H22

Electron spin resonance studies on layered van-der-Waals magnets — •Joyal John Abraham[1,2], Yurii Senyk[1], Alexey Alfonsov[1], Yuliia Shemerliuk[1], Sebastian Selter[1], Saicharan Aswartham[1], Bernd Büchner[1,3], and Vladislav Kataev[1] — [1]Leibniz IFW Dresden, D-01069 — [2]Institute for Solid State and Materials Physics, TU Dresden, D-01069 — [3]Institute for Solid State and Materials Physics and Wurzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, D-01062

Magnetic van-der-Waals (vdW) materials are compounds in which the planes consisting of magnetic atoms are held by weak vdW bonds. With a striking advantage of mechanical exfoliation to produce atomically thin layers, they are considered as promising candidates for studying exotic quantum phenomena and device application. Here, we present the investigation of magnetic vdW single crystals $Mn_2P_2S_6$ and $MnNiP_2S_6$, using high field/frequency electron spin resonance. Frequency dependence of resonance field reveals a change of the anisotropy from easy-axis-like in the pure Mn compound to an easy-plane-like in the mixed compound. Temperature dependence of resonance field and linewidth for in-plane and out-of-plane orientations of magnetic field reveals a shift in resonance from the paramagnetic position even above the transition temperature (T_N). This could be indicative of the presence of quasi-static spin-spin short-range correlations and hence provides insight about magnetic dimensionality of the studied material.

TT 12.11 Tue 12:15 H22

Magnon excitations, spin-lattice coupling and the emerging anisotropic nature of short-range order in van-der-Waals ferromagnets — M. Jonak[1], J. Arneth[1], A. Elghandour[1], E. Waldendy[1], S. Spachmann[1], C. Koo[1], M. Abdel-Hafiez[2], S. Selter[3], S. Aswartham[3], and •Rüdiger Klingeler[1] — [1]Kirchhoff Institute for Physics, Heidelberg University, Germany — [2]Dep. of Physics & Astronomy, Uppsala University, Sweden — [3]IFW Dresden, Germany

CrI_3 and $Cr_2Ge_2Te_6$ are quasi-2D semiconducting van der Waals ferromagnets which evolve long-range order down to the single- or double-layer limit. Quantitative determination of magnetic anisotropy and spin-lattice coupling are crucial to further exploit these materials. We report ferromagnetic resonance studies in a broad frequency regime of 30 - 330 GHz and in magnetic fields up to 18 T and high-resolution capacitance dilatometry. Our data prove significant magnetoelastic coupling and provide quantitative values of the uniaxial pressure effects. Modelling the magnon branches in CrI_3 by means of a domain-based ferromagnetic resonance model provides the microscopic parameters such the anisotropy gap of 80 GHz at 2 K which remarkably remains finite at T_C and vanishes only above 80 K. In addition, we detect short-range magnetic correlations up to at least 160 K. Notably, the nature of the short-range correlations in CrI_3 changes, confirming the importance of spin-orbit coupling for the evolution of long-range ferromagnetism which develops from magnetically anisotropic short-range order.

TT 12.12 Tue 12:30 H22

Orbital order and nematic instability in the antiferromagnetic phase of $BaCoS_2$ — •Benjamin Lenz[1], Michele Fabrizio[2], and Michele Casula[1] — [1]Institut de minéralogie, de physique des matériaux et de cosmochimie (IMPMC), Sorbonne University - CNRS - MNHN, Paris, France — [2]Scuola Internazionale Superiore di Studi Avanzati (SISSA), Trieste, Italy

We present evidence for a nematic instability in the antiferromagnetic insulating phase of $BaCoS_2$, which shows a Néel transition at a surprisingly high temperature of $T_N \sim 300$K. Based on *ab initio* simulations, we discuss several competing orders in terms of magnetic order, orbital composition and structural distortions to identify a set of nematic and orbital ordered states as possible candidates for the ground state. From these considerations we derive an effective spin-model of $J_1 - J_2$ type and discuss the consequences of the most probable, orbital ordered ground state for its parametrization. We finally identify a driving mechanism which allows to explain the high Néel temperature by $\mathcal{C}_4$-symmetry breaking through orbital order and draw parallels to other quasi-2D materials such as pnictides.

TT 12.13 Tue 12:45 H22

Tuning the multiorbital Mott transition of $BaCoS_2$ — •Haneen Abushammala[1,2], Yannick Klein[1], and Andrea Gauzzi[1] — [1]IMPMC, Sorbonne University, 4, place Jussieu, 75005 Paris, France — [2]Institute for Experimental Physics IV, Ruhr-Universität Bochum, Germany

The quasi-2D $BaCoS_2$ system displays an unusual Mott state concomitant with a stipe-type antiferromagnetic (AFM) ordering at T_N=305 K in a square-lattice of Co^{2+}. Electron doping by partial Co/Ni substitution, or hydrostatic pressure drives the system into a paramagnetic and Fermi Liquid (FL) metallic phase. Interestingly, this metal-insulator transition (MIT) is not accompanied by any significant structural distortion, which offers ideal conditions to investigate the FL to non-FL crossover in a model square-lattice system in the regime of moderate electronic correlations typical of sulphides. In order to investigate the interplay between AFM order and Mott state, we have studied the effect of chemical pressure and hole doping on the AFM order by partially substituting Sr and K for Ba respectively. Contrary to the case of hydrostatic pressure, we find that chemical pressure significantly reduces T_N down to 240 K for a substitution level of 8 at%, corresponding to an effective pressure of 0.3 GPa. The K-substitution is found to induce similar suppression of the AFM order as compared to the Sr-substitution. However, its sizable value of Sommerfeld coefficient (5.7 mJ/mol.K^2) suggests a metallic state induced by hole doping. Studies on single crystals may unveil whether the metallic state induced by K-doping displays FL-properties.

TT 13: Quantum Dots, Quantum Wires, Point Contacts

Time: Tuesday 9:30–11:00 Location: H23

TT 13.1 Tue 9:30 H23

Precession of entangled spin and pseudospin in double quantum dots — •Christoph Rohrmeier and Andrea Donarini — University Regensburg

Quantum dot spin valves are characterized by exchange fields [1] which induce spin precession and generate anomalous spin resonances [2]. Analogous effects have been studied in double quantum dots, in which the orbital degree of freedom replaces the role of the spin in the valve configuration [3]. We generalize, now, this setup to allow for arbitrary spin and orbital polarization of the leads, thus obtaining an even richer variety of current resonances, stemming from the entangled precession dynamics of the spin and pseudospin [4]. We observe for both vectors a delicate interplay of decoherence, pumping and precession which can only be understood by including the dynamics of the spin-pseudospin correlators. The results are obtained in the framework of a generalized master equation within the cotunneling approximation and are complemented by a coherent sequential tunneling model.

[1] Braun et al., Phys. Rev. B 70 (2004) 195345
[2] Hell et al., Phys. Rev. B 91 (2015) 195404
[3] Rohrmeier et al., Phys. Rev. B 103 (2021) 205420
[4] Rohrmeier et al., Phys. Rev. B 105 (2022) 205418

TT 13.2 Tue 9:45 H23

Pair-amplitude dynamics in superconductor-quantum dot hybrids — •Markus Heckschen and Björn Sothmann — Universität Duisburg-Essen, Duisburg, Deutschland

We consider a three-terminal system consisting of a quantum dot strongly coupled to two superconducting reservoirs in the infinite gap limit and weakly coupled to a normal metal. Using a real-time diagrammatic approach, we calculate the dynamics of the proximity-induced pair amplitude on the quantum dot. We find that after a quench the pair amplitude shows pronounced oscillations with a frequency determined by the coupling to the superconductors. In addition, it decays exponentially on a time scale set by the coupling to the normal metal. Strong oscillations of the pair amplitude occur also when the system is periodically driven both in the adiabatic and fast-driving limit. We relate the dynamics of the pair amplitude to the Josephson and Andreev current through the dot to demonstrate that it is an experimentally accessible quantity.

[1] M. Heckschen and B. Sothmann, Phys. Rev. B 105 (2022) 045420

TT 13.3 Tue 10:00 H23

Staggered spin-orbit interaction in a nanoscale device — Lauriane Contamin[1], Tino Cubaynes[1], William Legrand[1], •Magdalena Marganska[2], Matthieu Desjardins[1], Matthieu Dartiailh[1], Zaki Leghtas[1,3,4], Andre Thiaville[5], Stanislas Rohart[5], Audrey Cottet[1], Matthieu Delbecq[1], and Takis Kontos[1] — [1]Laboratoire de Physique de l'Ecole Normale Superieure, ENS, Universite PSL, CNRS, Sorbonne Universite, Universite Paris-Diderot, Sorbonne Paris Cite, Paris, France — [2]Institute for Theoretical Physics, University of Regensburg, Germany — [3]QUANTIC Team, INRIA de Paris, Paris, France — [4]Centre Automatique et Systemes, Mines Paris-Tech, PSL Research University, Paris, France — [5]Laboratoire de Physique des Solides, Universite Paris-Saclay, CNRS, UMR 8502, Orsay, France

The coupling of the spin and the motion of charge carriers is an important ingredient for the manipulation of the spin degree of freedom and for the emergence of topological matter. Creating domain walls in the spin-orbit interaction at the nanoscale may turn out to be a crucial resource for engineering topological excitations suitable for universal topological quantum computing or for new schemes for spin quantum bits. Realizing this in natural platforms remains a challenge. Using high resolution circuit quantum electrodynamics magneto-spectroscopy, we show how this can be implemented in carbon nanotubes with a staggered synthetic spin-orbit interaction induced by two lithographically patterned magnetically textured gates.

TT 13.4 Tue 10:15 H23

Jahn-Teller effects in charge transport through single-molecule junctions: a hierarchical equation of motion approach — •Christoph Kaspar and Michael Thoss — University of Freiburg

Molecules with degenerate electronic states may exhibit Jahn-Teller effects [1]. In this contribution, we investigate charge transport through such molecules bound to metal electrodes within a molecular junction [2]. The study employs the hierarchical equation of motion approach [3,4] to open quantum system dynamics. This method generalizes perturbative master equation methods by including higher-order contributions as well as non-Markovian memory, thus allowing for a systematic convergence of the results. Extending previous studies [5], we find that the molecule can become trapped in a nonconducting state resulting in a current-blockade, out of which only higher-order processes such as cotunneling provide an escape mechanism.

[1] M. O'Brien *et al.*, Am. J. Phys. **61**, 688 (1993)
[2] C. Kaspar *et al.*, Phys. Rev. B **105**, 195435 (2022)
[3] Y. Tanimura, J. Chem. Phys. **153**, 020901 (2020)
[4] C. Schinabeck *et al.*, Phys. Rev. B **94**, 201407R (2016)
[5] M. Schultz *et al.*, Phys. Rev. B **77**, 075323 (2008)

TT 13.5 Tue 10:30 H23

Evolution of single-level-model parameters in the mechanically controllable break junctions — •M. Lokamani[1,2], F. Kilibarda[2], F. Günther[3], J. Kelling[1], A. Strobel[2], P. Zahn[2], G. Juckeland[1], K. Gothelf[4], E. Scheer[5], S. Gemming[6], and A. Erbe[2] — [1]FWCC, HZDR, Dresden, Germany — [2]FWIO, HZDR, Dresden, Germany — [3]IFSC, São Carlos, Brazil — [4]iNANO, Aarhus, Denmark — [5]Department of Physics, Uni Konstanz, Germany — [6]Institute of Physics, TU Chemnitz, Germany

The electrical properties of single molecules can be investigated using atomically sharp metallic electrodes in mechanically controllable break junctions (MCBJs). The current-voltage (IV) characteristics of single molecules in such junctions are influenced by the binding positions of the end groups on the tip-facets and tip-tip separation. In this talk, we present MCBJ experiments on N,N'-Bis(5-ethynylbenzenethiol-salicylidene)ethylenediamine (Salen). We discuss the evolution of the single level model (SLM) parameters namely, a) the energetic level ϵ of the dominant conducting channel and b) the coupling Γ of the dominant conducting channel to the metallic electrodes. The SLM-parameters were evaluated for IV-curves recorded during opening measurements and fitted to the single level model. We propose a novel, high-throughput approach to model the evolution of the SLM-parameters and explain the recurring peak-like features in the experimentally measured evolution of Γ with increasing tip-tip separation, which we relate to the deformation of the molecule and the sliding of the anchor group above the electrode surface.

TT 13.6 Tue 10:45 H23

Relaxation dynamics in a Hubbard trimer and tetramer coupled to fermionic baths: antiferromagnetic order and persistent spin currents — •Nikodem Szpak[1], Gernot Schaller[2], Friedemann Queisser[2], Ralf Schützhold[2,3], and Jürgen König[1] — [1]Theoretische Physik, Universität Duisburg-Essen, Lotharstr. 1, 47048 Duisburg — [2]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden — [3]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden

We study relaxation dynamics in a strongly-interacting three and four-site Fermi-Hubbard system (quantum dots) coupled to environment represented by fermionic baths. Starting with an ab initio approach, we derive several variants of the Lindblad master equation for the quantum dots systems by applying different approaches: local and global, secular and coherent [1,2]. At low temperatures, depending on the particular parameter ratios and applied approximations, the system tends to or destroys antiferromagnetic order [2]. In three quantun dots, the system becomes spin-frustrated and relaxes to a stable persistent spin current.

[1] E. Kleinherbers, N. Szpak, J. König, and R. Schützhold, Phys. Rev. B 101, 125131
[2] G. Schaller, F. Queisser, N. Szpak, J. König, and R. Schützhold, Phys. Rev. B 105, 115139

TT 14: Many-Body Quantum Dynamics 2 (joint session DY/TT)

Time: Tuesday 11:30–13:00 Location: H20

TT 14.1 Tue 11:30 H20

Disorder-free localization transition in a two-dimensional lattice gauge theory — •Nilotpal Chakraborty[1], Markus Heyl[1,2], Petr Karpov[1], and Roderich Moessner[1] — [1]Max Planck Institute for physics of complex systems, Dresden — [2]University of Augsburg, Augsburg

While the nature of the quantum localization transition (QLT) is still debated for conventional many-body localization, here we provide the first comprehensive characterization of the QLT in two dimensions (2D) for a disorder-free case. Disorder-free localization can appear in homogeneous 2D LGTs such as the U(1) quantum link model (QLM) due to an underlying classical percolation transition fragmenting the system into disconnected real-space clusters. Building on the percolation model, we characterize the QLT in the U(1) QLM through a detailed study of the ergodicity properties of finite-size real- space clusters via level-spacing statistics and localization in configuration space. We argue for the presence of two regimes - one in which large finite-size clusters effectively behave non-ergodically, a result naturally accounted for as an interference phenomenon in configuration space and the other in which all large clusters behave ergodically. As one central result, in the latter regime we claim that the QLT is equivalent to the classical percolation transition and is hence continuous. Utilizing this equivalence we determine the universality class and critical behaviour of the QLT from a finite-size scaling analysis of the percolation problem.

TT 14.2 Tue 11:45 H20

Quantifying local memory in disordered systems across the ETH-MBL transition — •Sebastian Wenderoth and Michael Thoss — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg

Thermalization decribes the process of a system reaching thermal equilibrium with its environment. The asymptotic state solely depends on a few macroscopic parameters of the environment. Hence, the information about the initial state is lost during the process. Many-body localized systems fail to thermalize due to the absence of transport, and thus, some information about the initial state is retained in local observables at all times.

Based on the time-evolution of a subsystem, we present a concept which can be used to quantify the influence of the initial state on local observables. Using this approach, we investigate local memory in the XXZ Heisenberg spin chain with random local disorder, a paradigmatic model exhibiting a transition from thermalizing to localized dynamics. We discuss the loss of local information and identify different delocalization mechanisms.

TT 14.3 Tue 12:00 H20

Dynamically Induced Exceptional Phases in Quenched Interacting Semimetals — •Carl Lehmann[1], Jan Carl Budich[1], and Michael Schüler[2] — [1]TU Dresden, Dresden, Germany — [2]Paul Scherrer Institute, Villigen, Switzerland

We report on the dynamical formation of exceptional degeneracies in basic correlation functions of nonintegrable one- and two-dimensional systems quenched to the vicinity of a critical point. Remarkably, fine-tuned semimetallic points in the phase diagram of the considered systems are thereby promoted to topologically robust non-Hermitian (NH) nodal phases emerging in the coherent time evolution of a dynamically equilibrating system. Using nonequilibrium Greens function methods within the conserving second Born approximation, we predict observable signatures of these NH nodal phases both in equilibrated spectral functions and in the nonequilibrium dynamics of single-particle density matrix functions.

TT 14.4 Tue 12:15 H20

Nontrivial damping of quantum many-body dynamics — •Tjark Heitmann[1], Jonas Richter[2], Jochen Gemmer[1], and Robin Steinigeweg[1] — [1]Department of Physics, University of Osnabrück, Germany — [2]Department of Physics and Astronomy, University College London, UK

Understanding how the dynamics of a given quantum system with many degrees of freedom is altered by the presence of a generic perturbation is a notoriously difficult question. Recent works predict that, in the overwhelming majority of cases, the unperturbed dynamics is just damped by a simple function, e.g., exponentially. While these predictions rely on random-matrix arguments and typicality, they can only be verified for a specific physical situation by comparing to the actual solution or measurement. Crucially, it also remains unclear how frequent and under which conditions counterexamples to the typical behavior occur. Here, we discuss this question from the perspective of projection-operator techniques, where exponential damping of a density matrix occurs in the interaction picture but not necessarily in the Schrödinger picture. We show that a nontrivial damping in the Schrödinger picture can emerge if the dynamics in the unperturbed system possesses rich features, for instance due to the presence of strong interactions. This suggestion has consequences for the time dependence of correlation functions. We substantiate our theoretical arguments by large-scale numerical simulations of charge transport in the extended Fermi-Hubbard model with nearest-neighbor interactions as perturbations to the integrable reference system.

TT 14.5 Tue 12:30 H20

Effect of electron-electron interaction on the spectral statistics in circular sector graphene billiards — •Xianzhang Chen[1,2] and Liang Huang[1] — [1]Lanzhou Center for Theoretical Physics, and Key Laboratory for Magnetism and Magnetic Materials of MOE, Lanzhou University, Lanzhou, Gansu 730000, China — [2]Université de Strasbourg, CNRS, Institut de Physique et Chimie des Matériaux de Strasbourg, UMR 7504, F-67000 Strasbourg, France

The spectral statistics is a fundamental issue in quantum chaos and has been used widely as a measure to probe the complexity of the underlying quantum systems. In this work, we adopt the one-orbital mean-field Hubbard model to investigate the effect of many-body interactions on the spectral statistics of circular sector graphene billiards. It is found that the spectral statistics are insensitive to the Hubbard interaction U for most of the energy ranges, except for energies around the Dirac point. We choose two representative systems, whose spectral statistics follow Poisson and Gaussian orthogonal ensemble (GOE) when $U = 0$, respectively. As U increases, for both cases, the spectral statistics moves toward GOE. However, after passing a critical value U_c, the spectral statistics turns back toward Poisson as U is increased further, due to the emerging gap and henceforth distinct behaviors of the quasiparticles. In addition, the energies above and below the Dirac point may exhibit different spectral statistics. These results uncover the intriguing connection between Hubbard interaction and the spectral statistics in graphene sector billiards. A physical picture is provided to understand these effects.

TT 14.6 Tue 12:45 H20

Anisotropy-mediated localization — •Ivan Khaymovich — Nordic Institute for Theoretical Physics, Stockholm, Sweden

Recently, the standard picture of Anderson localization transition in d-dimensional long-range (e.g. dipolar) systems has been argued due to several reported counterintuitive examples of (at least power-law) localization beyond the convergence of the perturbation theory. In addition, wave-function spatial decay rates obey a "mysterious" duality [1] mapping different powers 'a' of power-law bending symmetrically around the critical point a=d.

In my talk, I address this intriguing question, present a general approach applicable to all such models, and uncover the role of correlations and the origin of the above duality [2]. The phenomenon of the correlation-induced localization [2] is just the very peak of the iceberg in this field. Therefore I will focus on the effects of anisotropy [3] in dipolar system and show the reentrant localization governed by the anisotropy parameter given by the tilt of an electric field. Note that the range of systems is also not limited by the dipolar systems, but includes also the Weyl semimetals, ultracold atoms, Rydberg excitations in the optical traps and many others.

Literature: [1] X. Deng, V. E. Kravtsov, G. V. Shlyapnikov and L. Santos, Phys. Rev. Lett. 120, 110602 (2018). [2] P. Nosov, I. M. Khaymovich, V. E. Kravtsov, Correlation-induced localization Phys. Rev. B 99, 104203 (2019) [arXiv:1810.01492] [3] X. Deng, A. L. Burin, I. M. Khaymovich, Anisotropy-driven localization transition in quantum dipoles [arXiv:2002.00013]

TT 15: Nano- and Optomechanics

Time: Tuesday 11:15–12:45 Location: H23

TT 15.1 Tue 11:15 H23

Mechanical frequency control in inductively coupled electromechanical systems — •Thomas Luschmann[1,2,3], Philip Schmidt[1,2], Frank Deppe[1,2,3], Achim Marx[1], Alvaro Sanchez[4], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [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, Munich, Germany — [4]Department of Physics, Universitat Autonoma de Barcelona, Bellaterra, Spain

Nano-electromechanical systems couple mechanical motion to superconducting quantum circuits at microwave frequencies. While traditional, capacitive coupling strategies operate in the weak coupling regime, inductive coupling schemes based on partially suspended superconducting interference devices (SQUID) have demonstrated significantly improved coupling rates. Such systems are expected to allow for the exploration of phenomena beyond the linearized opto-mechanical interaction. Here, we present an investigation into the tuning of the mechanical resonance frequency in an inductively coupled system. The experimental data quantitatively corroborates theoretical predictions for SQUID-based electromechanical systems. In addition, we observe a magnetic field dependent tuning of the mechanical resonance frequency, which we attribute to an effective interaction of the atomic lattice and the superconducting vortex lattice.

TT 15.2 Tue 11:30 H23

Current-induced forces in nano-electromechanical systems: A hierarchical equations of motion approach — •Samuel Rudge and Michael Thoss — Physikalisches Institut, Albert-Ludwigs Universität Freiburg

Current-induced forces in nanostructures provide valuable insight into the mechanisms of nonequilibrium charge transport through nanoelectromechanical systems [1]. In this contribution, we investigate specifically the electronic friction in molecular junctions using the hierarchical equations of motion approach [2-3]. Since this method is, in principle, numerically exact, it allows us to extend previous studies [4] beyond the Born-Markov approximation and incorporate strong intrasystem interactions. To demonstrate the approach, we consider a resonant level model coupled to a low-frequency vibrational mode, which is treated semi-classically, and reproduce the exact electronic friction known from nonequilibrium Green's function theory [4]. We then also incorporate a high-frequency vibrational mode, which is strongly coupled to the electronic degrees of freedom and is treated fully quantum mechanically.

[1] J. T. Lü *et al.*, Phys. Rev. B **85**, 245444 (2012)
[2] Y. Tanimura, J. Chem. Phys. **153**, 020901 (2020)
[3] J. Bätge *et al.*, Phys. Rev. B **103**, 235413 (2021)
[4] W. Dou *et al.*, J. Chem. Phys. **143** 054103 (2015)

TT 15.3 Tue 11:45 H23

Generation of coherent acoustic phonons at the atomic scale with femtosecond Coulomb forces — •Shaoxiang Sheng[1], Anne-Catherine Oeter[1], Mohamad Abdo[1], Kurt Lichtenberg[1], Mario Hentschel[3], and Sebastian Loth[1,2] — [1]University of Stuttgart, Institute for Functional Matter and Quantum Technologies, Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany — [3]University of Stuttgart, 4th Physics Institute, Stuttgart, Germany

Coherent acoustic phonons enable ultrafast control of solids and have been exploited for applications in various acoustic devices. We find that localized coherent acoustic phonon wavepackets can be launched by THz-induced ultrafast Coulomb forces in a scanning tunneling microscope (STM) junction. The wavepackets induce an ultrafast displacement of the surface with several picometers amplitude and propagate into the sample with low losses. The surface displacement can be precisely controlled by varying the tip-sample distance. This nonthermal femtosecond force excitation enables localized measurements of phonon propagation with nanometer spatial resolution, can be used for diagnostics below surfaces and opens new perspectives in exploiting coherent phonons at the atomic scale.

TT 15.4 Tue 12:00 H23

Josephson optomechanics — •Surangana Sen Gupta[1], Bjoern 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

Optomechanical phenomena can be investigated in the microwave regime using a circuit-QED setup combining superconducting microwave cavities and a mechanical degree of freedom. In conventional optomechanics the cavity is usually driven to a coherent state by a laser. In contrast, in circuit optomechanics, the cavity can be driven by inelastic tunneling in a Josephson junction, which provides a large inherent non-linearity and leads to complex quantum states of light [1]. Here, we theoretically investigate a superconducting cavity with a single mode ω_0 coupled to a mechanical resonator. The cavity is driven by a dc-biased Josephson junction at $2eV_{dc} = p\hbar\omega_0$ where each Cooper pair excites $p = 1, 2, 3$ photons.
(i) We characterise signatures of the mechanics in the emission spectrum for squeezed light ($p = 2$) and for the $p = 3$ case, which is challenging for optical cavities, but easily realised in our microwave cavities. The inherent nonlinearity not only allows efficient driving at $p \geq 2$, but can also drastically change the spectrum at $p = 1$, where for stronger driving Mollow-like features arise. (ii) We calculate heating and cooling rates for the mechanical degree of freedom and find in the non-linear regime enhanced and non-monotonous rates.
[1] G. C. Ménard *et al.*, Phys. Rev. X **12**, 021006 (2022).

TT 15.5 Tue 12:15 H23

Magnomechanics in suspended magnetic beams — Kalle S. U. Kansanen[1], •Camillo Tassi[2], Harshad Mishra[3], Mika A. Sillanpää[3], and Tero T. Heikkilä[1] — [1]Department of Physics and Nanoscience Center, University of Jyväkylä, P.O. Box 35 (YFL), FI-40014 Jyväskylä, Finland — [2]Donostia International Physics Center, 20018 Donostia-San Sebastian, Spain — [3]Department of Applied

Physics, Aalto University, P.O. Box 15100, FI-00076 Aalto, Finland

Cavity optomechanical systems have become a popular playground for studies of controllable nonlinear interactions between light and motion. An alternative scheme with much smaller footprint is provided by magnomechanics, where phonons interact with magnons, instead of photons. Here, we consider the magnomechanical interaction occurring in a suspended magnetic beam, a scheme in which both magnetic and mechanical modes physically overlap and can be detected and also driven individually. We show that a sizable interaction - originated from both magnetoelastic and demagnetizing coupling - can be produced if the beam has some initial static deformation.

TT 15.6 Tue 12:30 H23

Improving device parameters in nanotube microwave optomechanics — Nicole Kellner, •Fabian Stadler, Niklas Hüttner, and Andreas K. Hüttel — Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany

In recent work [1,2], we have demonstrated optomechanical coupling between a carbon nanotube with an embedded quantum dot and a coplanar microwave resonator. The experiment displayed enhancement of the coupling by several orders of magnitude via the nonlinearity of Coulomb blockade. The resulting novel optomechanical system can have figures of merit close to several interesting parameter regimes, as, e.g., strong optomechanical coupling (with hybridization of vibrons and photons) and the quantum coherent limit (where manipulation is faster than thermal decoherence). With this in mind, here we discuss our ongoing work to improve the components of this system, the optomechanical coupling, and its adressing and readout. — [1] S. Blien *et al.*, Nat. Comm. **11**, 1636 (2020); [2] N. Hüttner *et al.*, in preparation.

TT 16: Correlated Electrons: Method Development

Time: Wednesday 9:30–13:15 Location: H10

Invited Talk TT 16.1 Wed 9:30 H10

Multimethod, multimessenger approaches to models of strong correlations — •Thomas Schäfer — Max Planck Research Group "Theory of Strongly Correlated Quantum Matter" (SCQM), Max Planck Institute for Solid State Research, Stuttgart, Germany

The Hubbard model is the paradigmatic model for electronic correlations. In this talk I present a general framework for the reliable calculation of its properties, which we coined multi-method, multi-messenger approach. I will illustrate the power of this approach with three recent studies: (i) an extensive synopsis of arguably all available finite-temperature methods for the half-filled Hubbard model on a simple square lattice in its weak-coupling regime, fully clarifying the impact of spin fluctuations and tracking their footprints on the one- and two-particle level, (ii) a complementary subset of those applied to the Hubbard model on a triangular geometry, exhibiting the intriguing interplay of geometric frustration (magnetism) and strong correlations (Mottness) and (iii) a multi-method study of a model for magnetism in infinite-layer nickelates. These examples may work as a blueprint of similar future studies of strongly correlated systems.

TT 16.2 Wed 10:00 H10

Random phase approximation for gapped systems: Role of vertex corrections and applicability of the constrained random phase approximation — •Erik van Loon[1], Malte Rösner[2], Mikhail Katsnelson[2], and Tim Wehling[3] — [1]Lund University, Lund, Sweden — [2]Radboud University, Nijmegen, the Netherlands — [3]University of Bremen, Bremen, Germany

The many-body theory of interacting electrons poses an intrinsically difficult problem that requires simplifying assumptions. For the determination of electronic screening properties of the Coulomb interaction, the random phase approximation (RPA) provides such a simplification. Here we explicitly show that this approximation is justified for band structures with sizable band gaps. This is when the electronic states responsible for the screening are energetically far away from the Fermi level, which is equivalent to a short electronic propagation length of these states. The RPA contains exactly those diagrams in which the classical Coulomb interaction covers all distances, whereas neglected vertex corrections involve quantum tunneling through the barrier formed by the band gap. Our analysis of electron-electron interactions provides a real-space analogy to Migdal's theorem on the smallness of vertex corrections in electron-phonon problems. An important application is the increasing use of constrained RPA calculations of effective interactions. We find that their usage of Kohn-Sham energies accounts for the leading local (excitonic) vertex correction in insulators.

TT 16.3 Wed 10:15 H10

Consistency of potential energy in the diagrammatic vertex approximation — •Julian Stobbe and Georg Rohringer — Institute of Theoretical Physic, University of Hamburg, 20355 Hamburg, Germany

In the last decades, dynamical mean field theory (DMFT) and its diagrammatic extensions have been successfully applied to describe local and nonlocal correlation effects in correlated electron systems. Unfortunately, both of them suffer from intrinsic inconsistencies which lead to a violation of the Pauli principle (and related sum rules) as well as the conservation laws of the system. This limits the predictive power of these approaches as fundamental observables such as the kinetic and/or potential energies are not unambiguously defined. Here, we will discuss an approach to overcome the ambiguity in the calculation of the potential energy within the ladder dynamical vertex approximation (DΓA) by introducing an effective mass renormalization parameter in both the charge and the spin susceptibility of the system. The applicability of the method is then demonstrated on the half filled single-band Hubbard model on a three-dimensional cubic lattice. Furthermore, the solution method will be discussed, since the new method requires careful consideration of finite approximation of infinite Matsubara sums.

TT 16.4 Wed 10:30 H10

Vertex divergences in the Anderson impurity model - From real to imaginary frequencies — •Michael Meixner[1], Johannes Halbinger[2], Seung-Sup Lee[3], Fabian Kugler[4], Patrick Chalupa-Gantner[5], Alessandro Toschi[5], Jan von Delft[2], and Thomas Schäfer[1] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität München, Munich, Germany — [3]Department of Physics and Astronomy, National University, Seoul, South Korea — [4]Department of Physics and Astronomy, Rutgers University, Piscataway, NJ, USA — [5]Institute for Solid State Physics, TU Wien, Vienna, Austria

Generalized susceptibilities not only are at the heart of calculating momentum- and frequency-dependent response functions, but can also provide direct physical insights into local magnetic moment formation and Kondo screening. In particular, recent literature has investigated the implications of divergences of the irreducible vertex function on the Matsubara axis in the charge and particle-particle channels on the physics of the Anderson impurity model. In this study we examine the divergent properties of the two-particle irreducible vertex function in the Anderson impurity model employing the numerical renormalization group (NRG). In a first step data is benchmarked against state of the art results from continuous-time quantum Monte Carlo on the imaginary frequency axis. In a second step NRG allows us to access not only imaginary frequencies but also real frequencies via the Keldysh contour at very low temperatures and without analytic continuation.

TT 16.5 Wed 10:45 H10

Exact continuum representation of long-range interacting systems — •Andreas Alexander Buchheit[1], Torsten Kessler[1], Peter Schuhmacher[2], and Benedikt Fauseweh[2] — [1]Saarland University, 66123 Saarbrücken, Germany — [2]German Aerospace Center (DLR), 51147 Cologne, Germany

Continuum limits are a powerful tool in the study of many-body systems, yet their validity is often unclear when long-range interactions are present. In this work, we rigorously address this issue and put forth an exact representation of long-range interacting lattices that separates the model into a term describing its continuous analogue, the integral contribution, and a term that fully resolves the microstructure, the lattice contribution. For any system dimension, any lattice, any power-law interaction and for linear, nonlinear, and multi-atomic lattices, we show that the lattice contribution can be described by a differential operator based on the multidimensional generalization of the Riemann zeta function, namely the Epstein zeta function. Our representation provides a broad set of tools for studying the analytical properties of the system and it yields an efficient numerical method for the evaluation of the arising lattice sums. We benchmark its performance by computing classical forces and energies in three important physical examples, in which the standard continuum approximation fails: Skyrmions, defects in ion chains, and spin waves in a pyrochlore lattice with dipolar interactions. We demonstrate that our method exhibits the accuracy of exact summation at the numerical cost of an integral approximation.

TT 16.6 Wed 11:00 H10

Exotic phases in long-range interacting quantum lattices — Andreas A. Buchheit[1], •Torsten Kessler[1], Peter K. Schuhmacher[2], and Benedikt Fauseweh[2] — [1]Saarland University, Saarbrücken, Germany — [2]German Aerospace Center (DLR), Cologne, Germany

We provide a rigorous analysis of the effects of power-law long-range interactions on the phase diagram of a multi-dimensional quantum spin lattice. Starting from the discrete Hamiltonian, we use the recently developed singular Euler-Maclaurin expansion and derive an exact and parameter-free field theory that fully captures the effects due to the inherent discreteness of the lattice. For any lattice and any system dimension, we derive analytic expressions for the phase boundaries to ferromagnetic and anti-ferromagnetic phases and outline their dependence on the exponent of the power-law interaction and of the system dimension.

TT 16.7 Wed 11:15 H10

SU(2)-symmetric tensor network study of the classical Heisenberg model — •Philipp Schmoll[1], Augustine Kshetrimayum[1,2], Jens Eisert[1,2], Roman Orus[3,4,5], and Matteo Rizzi[6,7] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Helmholtz Center Berlin, 14109 Berlin, Germany — [3]Donostia International Physics Center, E-20018 San Sebastián, Spain — [4]Ikerbasque Foundation for Science, E-48013 Bilbao, Spain — [5]Multiverse Computing, E-20014 San Sebastián, Spain — [6]Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), 52425 Jülich, Germany — [7]Institute for Theoretical Physics, University of Cologne, D-50937 Köln, Germany

The classical Heisenberg model in two spatial dimensions constitutes one of the most paradigmatic spin models, taking an important role in statistical and condensed matter physics to understand magnetism. Despite its paradigmatic character controversies remain whether the model exhibits a phase transition at finite temperature. In this work, we make use of state-of-the-art tensor network approaches, representing the classical partition function in the thermodynamic limit over a large range of temperatures. By implementing an SU(2) symmetry in our tensor network, we are able to handle very large bond dimensions, which is crucial in detecting phase transitions. With decreasing temperatures, we find a rapidly diverging correlation length, whose behaviour is apparently compatible with the two main contradictory hypotheses known in the literature, namely a finite-T transition and asymptotic freedom, though with a slight preference for the second.

15 min. break

TT 16.8 Wed 11:45 H10

Matrix-product-state-based band-Lanczos solver for quantum cluster approaches — Sebastian Paeckel[1,2], Thomas Köhler[3], Salvatore R. Manmana[4], and •Benjamin Lenz[5] — [1]Arnold Sommerfeld Center of Theoretical Physics, University of Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Department of Physics and Astronomy, Uppsala University, Sweden — [4]Institute for Theoretical Physics, Georg August University of Göttingen, Germany — [5]Institut de minéralogie, de physique des matériaux et de cosmochimie (IMPMC), Sorbonne University, Paris, France

We present a matrix-product-states-based band-Lanczos method as a solver for quantum cluster techniques. Based on a traditional band-Lanczos technique for the calculation of the cluster Green's function, we introduce and motivate different convergence criteria and discuss their impact on the stability of the results at the example of the variational cluster approximation. The capabilities of this method to calculate the self-energy functional are demonstrated for Hubbard-like models on different cluster geometries. Finally, we show a finite-size scaling of order parameters using cluster sizes, which are out of reach for traditional exact-diagonalization-based solvers.

TT 16.9 Wed 12:00 H10

Hierarchical equations of motion approach to open quantum system dynamics: Matrix product state formulation in twin space — •Yaling Ke[1], Raffaele Borrelli[2], and Michael Thoss[1] — [1]Institute of Physics, Albert-Ludwig University Freiburg, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany — [2]DISAFA, Università di Torino, I-10095 Grugliasco, Italy

The hierarchical equations of motion (HEOM) approach is a numerically exact method to study the dynamics of open quantum systems with non-perturbative system-environment interaction and non-Markovian memory at finite temperatures. Although considerable progress has been made over the past few decades to extend the applicability of the HEOM approach, the numerical cost is still very expensive for reasonably large systems.

In this contribution, we present the twin-space formulation of the HEOM approach in combination with the matrix product state representation for open quantum systems coupled to a hybrid fermionic and bosonic environment. The key ideas of the approach are a reformulation of a set of differential equations for the auxiliary density matrices into a time-dependent Schrödinger-like equation for an augmented multi-dimensional wave function as well as its tensor decomposition into a product of low-rank matrices. The new approach facilitates accurate simulations of non-equilibrium quantum dynamics in larger and more complex open quantum systems with both factorized and correlated initial conditions.

TT 16.10 Wed 12:15 H10

Single-boson-exchange-fRG application to the two-dimensional Hubbard model at weak coupling — Sarah Heinzelmann[1], Kilian Fraboulet[1], Pietro Bonetti[2], Aiman Al-Eryani[1], Demetrio Vilardi[2], •Alessandro Toschi[3], and Sabine Andergassen[1] — [1]Eberhard Karls Universität Tübingen — [2]Max Planck Institut Stuttgart — [3]Technische Universität Wien

We illustrate the computational advantages of the recently introduced single-boson exchange (SBE) formulation for the one-loop functional renormalization group (fRG) applied to the two-dimensional Hubbard model. We present a detailed analysis of the physical susceptibilities and their evolution with temperature and interaction strength, both at half filling and finite doping. We find that the rest functions describing the corrections beyond the SBE contributions play a negligible role in the weak coupling regime. The SBE formulation of the fRG flow hence allows for a substantial reduction of the numerical effort in the treatment of the two-particle vertex function, paving a promising route for future multiboson and multiloop extensions.

TT 16.11 Wed 12:30 H10

Connecting real- and imaginary-frequency axis for two-particle many-body propagators — •Selina Dirnböck[1], Sebastian Huber[1], Seung-Sup Lee[2,3], Fabian Kugler[4], Jan von Delft[3], Karsten Held[1], and Markus Wallerberger[1] — [1]TU Wien, Austria — [2]Seoul National University, South Korea — [3]Ludwig-Maximilians-Universität München, Germany — [4]Rutgers University, New Jersey, USA

Two-particle response functions are a centerpiece of quantum many-body physics, relating both to experiment, where they can be observed as susceptibilities, and to theory, where they form the basis of advanced self-consistent field theories. Yet, due to their size and complex structure, they are challenging to handle numerically.

Recently, two advances have been made to tackle this problem: firstly, the intermediate representation together with an overcomplete basis (IR+OB), which provides a highly efficient compression of propagators in imaginary frequency, and secondly, partial spectral functions (PSFs), which allow for the efficient evaluation in real frequency, by, for example, using the numerical renormalization group (NRG).

In this talk, we connect these two approaches: we show that the IR+OB and PSFs are intimately connected. We also show that the two-particle propagator obtained from NRG/PSFs on the real-frequency axis can be compressed efficiently using IR+OB on imaginary-frequency axis, reducing the memory demand by more than three orders of magnitude. Finally, we use the guidance from PSFs to develop a physical regularization scheme for the IR+OB.

TT 16.12 Wed 12:45 H10

Trie-based ranking of quantum many-body states — •Markus Wallerberger and Karsten Held — TU Wien, Vienna, Austria

Ranking bit patterns – finding the index of a given pattern in an ordered sequence – is a major bottleneck scaling up numerical quantum many-body calculations, as fermionic and hard-core bosonic states translate naturally to bit patterns. Traditionally, ranking is done by bisectioning search, which has poor cache performance on modern machines.

We instead propose to use tries (prefix trees), thereby achieving a two- to ten-fold speed-up in numerical experiments with only moderate memory overhead. For the important problem of ranking permutations, the corresponding tries can be compressed. These compressed "staggered" lookups allow for an additional speed-up while retaining the memory requirements of prior algorithms based on the combinatorial number system.

We use these improvements to go to larger system sizes for which three-and four-point propagators can be computed.

TT 16.13 Wed 13:00 H10

Tetranacci polynomials in solid state phyics — •Nico Leumer — IPCMS, CNRS, Strasbourg

In mesoscopic physics, state of the art theoretical research relies not solely but to large extend on numerical investigations. Naturally, support from analytical side is important whenever possible, in particular to appeal physical intuition. For the first time, I will introduce to a broader audience so called Tetranacci polynomials, which offer a generic technique to analytic diagonalize a variety of model Hamiltonians for finite system size and when open/free boundary conditions are imposed. As perspective, this approach is applicable on discrete physical (sub-) systems owing at least two degrees of freedom per atom, such as the Kitaev chain or the 1d Rashba-nanowire in magnetic field positioned on superconducting substrate. The use extends further to the famous Su-Schrieffer-Heeger model or to topological trivial tight-binding chains having nearest and next nearest neighbor hopping. In my presentation, I elaborate that Tetranacci polynomials extend Bloch's theorem and how they are related to eigenvectors and eigenvalues. Within the frame drawn by the illustrative example of the X-Y-chain in transverse magnetic field, I demonstrate how previous diagonalization approaches are recovered by the more general Tetranacci technique. The final part of my presentation is devoted to an overview of physically distinct systems hosting Tetranacci polynomials and their common spectral features overlooked in earlier studies.

[1] N. Leumer et al., J. Condens. Matter Phys. 32 445502 (2020)
[2] N. Leumer et al., Phys. Rev. B 103, 165432 (2021)

TT 17: Cryogenic Detectors and Cryotechnique

Time: Wednesday 9:30–12:00 Location: H22

TT 17.1 Wed 9:30 H22

TES sensors design for the CRESST experiment — •Francesca Pucci[1], Antonio Bento[1,2], Anna Bertolini[1], Lucia Canonica[1], Nahuel Ferreiro Iachellini[1,3], Abhiji Garai[1], Dieter Hauff[1], Athoy Nilima[1], Michele Mancuso[1], Federica Petricca[1], Franz Proebst[1], and Dominik Fuchs[1] — [1]Max-Planck-Institut für Physik, D-80805 München, Germany — [2]LIBPhys-UC, Departamento de Fisica, Universidade de Coimbra, P3004 516 Coimbra, Portugal — [3]Excellence Cluster Origins, D-85748 Garching, Germany

The CRESST experiment aims at the direct detection of sub-GeV dark matter particles via elastic scattering off nuclei in different target crystals at cryogenic temperatures. Each detector consists of an absorber crystal and a Transition Edge Sensors (TES), which measures the temperature variations caused by an energy deposition in the crystal. The TES are made of tungsten thin films and they are operated in the middle of their superconducting transition, at around 15 mK. These very sensitive detectors allow for a leading energy threshold worldwide. The studies on the TES sensor design and its development at the Max Planck Institute for Physics are presented.

TT 17.2 Wed 9:45 H22

Beta spectrometry measurements with metallic magnetic calorimeters — •Michael Paulsen[1], Jörn Beyer[1], Christian Enss[2,6], Sebastian Kempf[3,6], Karsten Kossert[4], Martin Loidl[5], Riham Mariam[5], Ole Nähle[4], Philipp Ranitzsch[4], Matias Rodrigues[5], and Mathias Wegner[6,3] — [1]Physikalisch-Technische Bundesanstalt, Berlin, Germany — [2]Kirchhoff-Institute for Physics, Heidelberg University, Germany — [3]Institute of Micro- and Nanoelectronic Systems, Karlsruhe Institute of Technology, Germany — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [5]Université Paris-Saclay, CEA, List, Laboratoire National Henri Becquerel, Palaiseau, France — [6]Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, Germany

Precise beta spectra measurements are important for radionuclide metrology, the validation of theoretical calculations and nuclear medicine. Metallic Magnetic Calorimeters (MMCs) with the radionuclide sample embedded in a 4π absorber have proven to be among the best beta spectrometers in terms of energy resolution and threshold, linearity and detection efficiency, notably for low energy beta transitions. In this work, two measurements of the spectrum of the 2nd forbidden non-unique beta transition of ^{99}Tc ($Q^- = 297.5\,\mathrm{keV}$) are presented. They were acquired using two independent MMC based detectors in two different laboratories and show excellent agreement. The results suggest a spectral shape which deviates significantly from hitherto theoretical calculations and semi-empirical extrapolations at lower energies ($< 50\,\mathrm{keV}$) reported in the literature.

TT 17.3 Wed 10:00 H22

Low-noise, impedance matched current-sensing dc-SQUIDs for magnetic microcalorimeter readout — •Fabienne Bauer[1,2], Christian Enss[1], and Sebastian Kempf[1,2] — [1]Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institute of Micro- and Nanoelectronics Systems, Karlsruhe Institute of Technology, Hertzstraße 16, 76187 Karlsruhe

Direct-current superconducting quantum interference devices (dc-SQUIDs) are the devices of choice for reading out low-impedance cryogenic particle detectors such as magnetic microcalorimeters (MMCs). MMCs use a paramagnetic or superconducting temperature sensor, placed in a weak magnetic field and inductively coupled to a superconducting pickup coil, to convert deposited energy into a change of magnetic flux threading the pickup coil. The latter is sensed using a low-noise SQUID. To maximize sensitivity and hence energy resolving power, impedance matching between SQUID and pickup coil as well as a SQUID white noise level close to the quantum limit are crucial. As current-sensing SQUIDs with input inductances between 1 nH and 10 nH and suited for mK-operation temperatures are rarely or not at all commercially available, custom SQUIDs for MMC readout must be developed. In this context, we discuss design and performance of three current-sensing dc-SQUIDs impedance matched to MMCs that are foreseen for neutrino mass investigation, X-ray spectroscopy and mass spectrometry, respectively. To achieve low-noise performance, the SQUIDs rely on the use of cross-type Josephson junctions to minimize junction capacitance and hence readout noise.

TT 17.4 Wed 10:15 H22

Flux ramp modulation based hybrid microwave SQUID multiplexer — •Constantin Schuster[1,2], Mathias Wegner[1,2], Christian Enss[1], and Sebastian Kempf[1,2] — [1]Kirchhoff-Institute for Physics, Heidelberg University, Heidelberg — [2]Institute of Micro- and Nanoelectronic Systems, Karlsruhe Institute of Technology, Karlsruhe

For the readout of cryogenic detector arrays, microwave SQUID multiplexers (μMUXes) are presently being developed. Using non-hysteretic rf-SQUIDs, each multiplexer channel transforms the detector signal into a change of amplitude or phase of a microwave signal probing the resonance frequency of a superconducting resonator. In this way, numerous detectors can be simultaneously read out by coupling multiple resonators to a common transmission line. The resonator bandwidth is adjusted according to the detector speed and sets a lower limit for the frequency spacing of resonators. This limit, however, can in practice only be reached if the fabrication accuracy is very high. As a result, the channel density is very often limited by fabrication rather than the inherent channel capacity of the transmission line. We present a hybrid microwave SQUID multiplexer combining two frequency-division readout techniques to allow multiplexing a given number of detectors with only a fraction of readout resonators. We present insights of our approach based on information theory and discuss benefits and drawbacks using Monte-Carlo simulations. We further discuss the performance of a prototype device indicating that our technique is very well suited for reading out ultra-large bolometric detector arrays.

TT 17.5 Wed 10:30 H22

Transport properties of superconducting thin films and superconducting single-photon detectors — •Fabian Wietschorke[1], Stefan Strohauer[2], Rasmus Flaschmann[1], Lucio Zugliani[1], Christian Schmid[1], Sven Ernst[2], Stefanie Grotowski[2], Simone Spedicato[2], Björn Jonas[1], Mirco Metz[1], Kai Müller[1], and Jonathan Finley[2] — [1]Walter Schottky Institute and Department for Electrical and Computer Engineering, Technical University of Munich, 85748 Garching, Germany — [2]Walter Schottky Institute and Physics Department, Technical University of Munich, 85748 Garching, Germany

Superconducting single-photon detectors (SSPDs) play a crucial role in the rapidly growing field of quantum communication and computation. Hereby, NbTiN is an established candidate for superconducting thin films that is used as the active part of the SSPDs. To achieve high detection efficiencies, the superconducting properties of NbTiN films, deposited via magnetron sputtering, need to be optimized. In this contribution, we present transport measurements characterizing the influence of the deposition process onto the superconducting properties, which assists in a systematic optimization of the detectors. We are able to estimate detection efficiency and depairing current of the SSPDs, even before fabricating the nanostructures, utilizing the hotspot model and the Ginzburg-Landau model. Finally, we use the thin film transport measurements and detector measurements to assess the quality of our nanofabrication process.

15 min. break

TT 17.6 Wed 11:00 H22

Opimization of MoSi film deposition for superconducting single-photon detectors in the telecom c-band — •Stefanie Grotowski[1], Lucio Zugliani[2], Rasmus Flaschmann[2], Stefan Strohauer[1], Christian Schmid[2], Fabian Wietschorke[2], Sven Ernst[1], Simone Spedicato[1], Mirco Metz[2], Björn Jonas[2], Kai Müller[2], and Jonathan Finley[1] — [1]Walter Schottky Institute and Physics Department, Technical University of Munich, Germany — [2]Walter Schottky Institute and Department for Electrical and Computer Engineering, Technical University of Munich, Germany

Superconducting single-photon detectors (SSPDs) are a crucial building block for photonic quantum technologies. With regard to the telecommunication infrastructure, SSPDs sensitive in the telecom c-band are required. A promising material in this regard is MoSi, as it unites a small superconducting energy gap enabling high sensitivity while maintaining a high transition temperature. In this work we aim at optimizing the magnetron co-sputtering deposition to achieve high transition temperatures (T_c). We vary the stoichiometry and find maximized T_c values for Mo rich films until an upper limit of around 80% Mo is reached. Above this critical concentation grazing incidence diffration reveals the transition to a polycrystalline phase in the material. Moverover, the working pressure during deposition influences both T_c and structure as well. We find that a low working pressure improves the T_c, but a minimum pressure is required to ensure an amorphous deposition. Finally, with the optimized parameter set we measured a T_c of 8.4 K for 20 nm and 6.2 K for 4.5 nm thin films.

TT 17.7 Wed 11:15 H22

Superconducting single-photon detectors on lithium-niobate-on-insulator — •Christian Schmid[1], Rasmus Flaschmann[1], Lucio Zugliani[1], Stefan Strohauer[2], Björn Jonas[1], Fabian Wietschorke[1], Sven Ernst[2], Stefanie Grotowski[2], Simone Speticato[2], Mirco Metz[1], Kai Müller[1], and Jonathan Finley[2] — [1]Walter Schottky Institute and Department for Electrical and Computer Engineering, Technical University of Munich, Germany — [2]Walter Schottky Institute and Physics Department, Technical University of Munich, Germany

Superconducting single-photon detectors (SSPDs) are a key building block in photon-based quantum computation and communication. To realize a scalable photonic quantum computer, integration of single-photon sources, electronics and crucially SSPDs is necessary. One of the most promising material platforms for quantum photonic integration is lithium-niobate-on-insulator (LNOI), which offers a broad optical window and a large non-linearity.
In this work, we present the thin film superconducting properties of NbTiN grown on crystalline LNOI and compare them to films deposited on amorphous Si/SiO_2 wafer. SSPDs fabricated from films on both substrates are further characterized with respect to their quantum efficiency, dark count rate, recovery time and timing jitter.

TT 17.8 Wed 11:30 H22

Cooling performance of a 4 K two-stage pulse tube cryocooler in tilted operation along main azimuthal orientations — •Jack-Andre Schmidt[1,2], Bernd Schmidt[1,2], Jens Falter[1,2], and Andre Schirmeisen[1,2] — [1]Justus-Liebig-University Giessen — [2]TransMIT GmbH

Closed-cycle cryocoolers, here Gifford-McMahon (GM) type pulse tube cryocoolers (PTC), offer long measurement periods and low maintenance, but they exhibit undesired intrinsic effects due to the working principle [1]. Cooling performance of GM-type PTCs is strongly depending on the orientation and is set to be strictly vertical, which is not suitable for experiments where the cryostat needs to be tilted [2, 3]. We report an experimental study of the effect of tilting from vertical orientation on the cooling performance of a U-shaped 4 K pulse tube cryocooler (PTC) with 7 kW electrical input power. An investigation of cooling performance over tilt angles from 0 to 60 degree for selected azimuthal orientations of the PTC is performed. The non-coaxial arrangement of the tubes suggests an asymmetric cooling performance while tilting along the first or second stage heat exchanger due to natural convection in the pulse tubes [3]. The increase of no-load temperatures upon tilting by +/- 50 degree will be discussed. While the regime of tilt angles within 30 show moderate loss in cooling power an almost sudden decrease of cooling power is revealed and analyzed for high tilt angles.

[1] G. Thummes et al., Cryocoolers 9 (1997) 393
[2] T. Tsan et al., Cryogenics 117 (2021) 103323
[3] C. Risacher et al., IEEE 39 (2014)
[4] L. Zhang, et al., Cryogenics 51 (2011) 85

TT 17.9 Wed 11:45 H22

Cross Correlated Current Noise Thermometer for Milli-Kelvin Temperatures — •Christian Ständer, Pascal Willer, Nathalie Probst, Andreas Reifenberger, Andreas Reiser, Andreas Fleischmann, and Christian Enss — Kirchhoff Institute for Physics, Heidelberg University.

Within our search for easy-to-use and reliable thermometers for milli-Kelvin and micro-Kelvin temperatures we developed a noise thermometer, where the Johnson noise of a massive cylinder of high purity silver is monitored simultaneously by two current sensing dc-SQUIDs. Operating each SQUID in voltage bias mode in a 2-stage configuration allows to reduce the power dissipation of the SQUIDs to a minimum. To further reduce the parasitic effect of correlated amplifier noise, a mathematical method to suppress the noise coupled from the feedback to the input coil of the SQUIDs is introduced. By cross-correlating the two SQUID signals, the noise contribution of the read-out electronics is suppressed to a marginal level.
We recently assembled a first small series of such thermometers to best reliability, reproducibility and user friendliness. In the complete investigated temperature range from 4 K down to 5 mK, the measured noise power is linear in temperature. The 12 thermometers of the series agree within less than 0.1% in the complete temperature range and show a good agreement with the PTLS-2000 temperature scale. Also a new sensor material, with the goal of counteraction observed ageing effects, is introduced.

TT 18: Topological Insulators

Time: Wednesday 9:30–11:45 Location: H23

TT 18.1 Wed 9:30 H23

Exceptional topological insulators — •Michael Denner[1], Anastasiia Skurativska[1], Frank Schindler[1,2], Mark Fischer[1], Ronny Thomale[3], Tomás Bzdusek[1,4], and Titus Neupert[1] — [1]Department of Physics, University of Zurich, Switzerland — [2]Princeton Center for Theoretical Science, Princeton University, USA — [3]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany — [4]Condensed Matter Theory Group, Paul Scherrer Institute, Switzerland

Since their theoretical conception and experimental discovery, 3-dimensional topological insulators have become the focal point for research on topological quantum matter. Their key feature is a single Dirac electron on the surface, representing an anomaly: in purely 2D such a state can neither be regularized on a lattice nor in the continuum. I will introduce an analog in dissipative systems, which are described by non-Hermitian operators, the exceptional topological insulator (ETI). Like normal topological insulators, the ETI hosts exotic surface states. It is characterized by a bulk energy point gap and exhibits robust surface states that cover the bulk gap as a single sheet of complex eigenvalues or with a single exceptional point. Even though it does not require any symmetry to be stabilized, I will explain how this non-Hermitian topological phase can also be inferred using symmetry-indicators of the bulk Hamiltonian. Furthermore, I will demonstrate how the ETI can be induced in gapless solid-state systems and metamaterials, thereby setting a paradigm for non-Hermitian topological matter.

TT 18.2 Wed 9:45 H23

Berry curvature effects in high-harmonic generation in topological insulator surface states — •Vanessa Junk[1], Cosimo Gorini[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

When strong-field light is interacting with a solid, it acts as an a.c. bias accelerating electrons through the bandstructure and driving non-perturbative transitions. These processes can lead to the emission of high-order harmonics containing fingerprints of the materials properties. Since in topological insulator surface states scattering is strongly suppressed, signatures of coherent transport can be found in the resulting spectra.

Recently, high-harmonics generation from the surface states of the three-dimensional topological insulator Bi_2Te_3 has been observed experimentally [1]. Here, we show fully quantum mechanical simulations of the electron dynamics and compare them with the experimental results. We find that the Berry curvature can not only lead to high-harmonics polarized perpendicularly to incoming radiation but also to an alternating polarization of odd and even order harmonics. This being one of the key observations in the experiment suggests the importance of Berry curvature effects in coherent high-harmonics emission.

[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, R. Huber, Nature **593**, 385 (2021)

TT 18.3 Wed 10:00 H23

Spin-polarized surface state transport in gate-tunable topological insulator — •Linh Dang[1], Oliver Breunig[1], Henry Legg[2], and Yoichi Ando[1] — [1]1 II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany — [2]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

Topological insulators (TIs) possess helical spin-momentum locked surface states that can be harnessed to create a non-zero spin polarization by applying a current through the TI. Two opposite types of spin polarization have been reported on the same material, suggesting the interplay between topological surface state and Rashba spin splitting state of 2-dimensional surface electrons. These two contributing effects might be used to create a spin transistor device. In this report, we discuss the sign switching of the spin polarization by electrostatic gating based on data acquired from devices that were microfabricated on TI flakes.

TT 18.4 Wed 10:15 H23

Chern insulating phases and thermoelectric properties of EuO/MgO(001) superlattices — •Okan Koeksal and Rossitza Pentcheva — Department of Physics and Center of Nanointegration (CENIDE), University of Duisburg-Essen, 47057 Duisburg

The effect of confinement and strain on the topological and thermoelectric properties of $(EuO)_n/(MgO)_m(001)$ superlattices (SLs) are investigated by means of DFT + U + spin-orbit coupling (SOC) calculations in conjunction with semi-classical Boltzmann transport theory. A particularly strong effect is observed in the ferromagnetic $(EuO)_1/(MgO)_3(001)$ SL at the lateral lattice constant of MgO ($a = 4.24$ Å) where SOC opens a band gap of 0.51 eV due to an inversion between occupied localized Eu $4f$ and itinerant $5d$ conduction bands. This band inversion between bands of opposite parity is accompanied by a spin reorientation in the spin-texture along the contour of band surrounding the Γ point. The resulting Chern insulating phase with $C = -1$, confirmed by a single topological edge state, exhibits promising thermoelectric properties, i.e., a high Seebeck coefficient between 400 and 800 μVK^{-1}. Somewhat lower thermoelectric values are obtained for the ferromagnetic semimetallic $(EuO)_2/(MgO)_2(001)$ SL, where SOC also induces a band inversion and AHC with values up to –1.04 e^2/h. This work emphasizes the correlation between non-trivial topology and thermoelectricity in $(EuO)_n/(MgO)_m(001)$ SLs with broken time-reversal symmetry [1].

Support by the DFG within CRC/TRR80, project G3 is gratefully acknowledged.

[1] O. Köksal and R. Pentcheva, Phys. Rev. B **103**, 045135 (2021)

TT 18.5 Wed 10:30 H23

Stacking faults in weak topological insulators with time reversal symmetry — •Gabriele Naselli, Viktor Könye, and Ion Cosma Fulga — Leibniz-Institut für Festkörper-und Werkstoffforschung, Dresden, Germany

In experimental observation stacking faults can play a significant role in hiding the topological properties of topological insulators. The defects break lattice symmetries which can be required for the protection of the topological states in weak topological insulators. We studied stacking faults in $3D$ weak topological insulators like Bi_2TeI and $Bi_{14}Rh_3I_9$. Both these materials are formed by $2D$ topological insulating layers (with time reversal symmetry and quantum spin Hall effect) stacked on top of each other in the z direction with trivial insulating spacers between them. We have built a simple tight binding model for both of these materials and got the topological properties solving the eigenvalue problem numerically. We introduced a stacking fault in our model by shifting half of the system by a fraction of the unit cell in the z direction. We mapped the stacking surface in the WTI into a Su-Schrieffer-Heeger chain, considering the effective hoppings between the TI layers on the left and right side of the stacking fault. When all the TI layers on the left side are strongly interacting with the TI layers on the right side of the defect the corresponding SSH model is in the trivial phase and we did not find conducting states. Instead when the stacking fault has two weakly interacting TI layers at its boundaries the corresponding SSH chain is in the topological phase and we have found localized conducting states at the defect.

TT 18.6 Wed 10:45 H23

Dynamic impurities in two-dimensional topological insulator edge states — •Simon Wozny[1], Martin Leijnse[1], and Sigurdur I. Erlingsson[2] — [1]Division of Solid State Physics and NanoLund, Lund University, Box 118, S-22100 Lund, Sweden — [2]School of Science and Engineer- ing, Reykjavik University, Menntavegi 1, IS-101 Reykjavik, Iceland

Two-dimensional topological insulators host one-dimensional helical states at the edges. These are characterized by spin-momentum locking and time-reversal symmetry protects the states from backscattering by potential impurities. Magnetic impurities break time-reversal symmetry and allow for backscattering.

We have investigated the effects of random, aligned but harmonically rotating magnetic impurities. Using the time dependent Green's function (GF) for the system we calculate the time-averaged density of states (DOS) and extract the transmission via a Floquet scattering formalism. For slow driving the DOS and transmission match an average over static impurity orientations, whereas fast driving results in a flat low-energy DOS and transmission with resonances at higher energies related to Floquet sub-band crossings. Resonant driving leads to a nontrivial DOS and transmission. We also investigate the dependence on the ratio between potential and magnetic strength of the impurities.

TT 18.7 Wed 11:00 H23

Quantum phase transitions and a disorder-based filter in a Floquet system — •Bhargava Balaganchi Anantha Ramu, Sanjib Kumar Das, and Ion Cosma Fulga — IFW Dresden and Wurzburg-Dresden Cluster of Excellence ct.qmat, Helmholtzstrasse 20, 01069 Dresden, Germany

Two-dimensional periodically-driven topological insulators have been shown to exhibit numerous topological phases, including ones which have no static analog, such as anomalous Floquet topological phases. We study a two dimensional model of spinless fermions on a honeycomb lattice with periodic driving. We show that this model exhibits a rich mixture of weak and strong topological phases, which we identify by computing their scattering matrix invariants. Further, we do an in-depth analysis of these topological phases in the presence of spatial disorder and show the relative robustness of these phases against imperfections. Making use of this robustness against spatial dis-order, we propose a filter which allows the passage of only edge states, and which can be realized using existing experimental techniques.

TT 18.8 Wed 11:15 H23

Topological phases of Su-Schrieffer-Heeger alternating ladders — •Anas Abdelwahab — Leibniz Universität Hannover, Hannover, Germany

Alternating ladders are constructed from unit cells consisting of rungs with odd number of sites connected with rungs with even number of sites [1]. These systems can be constructed using several options of equivalent unit cells. Two one-site rungs connected with two two-site rungs as well as two three-site rungs connected with two two-site rungs are investigated. Rich phase diagrams of topological insulating phases separated by critical lines are identified using the Su-Schrieffer-Heeger (SSH) model that describe such ladder systems. The phase diagrams depend on the choices between the equivalent unit cells. One could identify cases with flat bands close to the Fermi level. In principle, these simple models can be realized in designer quantum materials such as artificial lattices constructed by manipulation of atoms using a tip of scanning tunnelling microscope (STM) [2,3].

[1] K. Essalah, A. Benali, A. Abdelwahab, E. Jeckelmann, and R. T. Scalettar, Phys. Rev. B 103, 165127 (2021)
[2] R. Drost, T. Ojanen, A. Harju and P. Liljeroth, Nat. Phys. 13, 668 (2017)
[3] M. N. Huda, S. Kezilebieke, T. Ojanen, R. Drost and P. Liljeroth, npj Quantum Materials 5, 17 (2020)

TT 18.9 Wed 11:30 H23

Coulomb-blockade spectroscopy in topological insulator-superconductor hybrid devices — •Benedikt Frohn, Tobias W. Schmitt, Wilhelm Wittl, Dennis Heffels, Michael Schleenvoigt, Abdur R. Jalil, Detlev Grützmacher, and Peter Schüffelgen — Peter Grünberg Institut, Forschungszentrum Jülich & JARA Jülich-Aachen Research Alliance, D-52425 Jülich, Germany

In the search for fault tolerant quantum computing, Majorana zero modes resemble a promising platform [1]. We investigate an island of a topological insulator (TI) nanoribbon, $(Bi,Sb)_2Te_3$, proximitized with a superconductor (S) for signatures of these states using Coulomb-blockade spectroscopy. One possible signature would be a change in charge periodicity once the island is tuned into the topological regime. We successfully created tunneling barriers made from Al_2O_3 and obtained the characteristic Coulomb diamond structure. Nb provides excellent interface transparency towards TI and was capped *insitu*, yet we found no change in charge periodicity. Al, however, is known to show these signatures in comparable experiments. Since Al diffuses heavily into the TI when put directly into contact, we fabricated Josephson junctions (JJs) with different thin interlayers between $(Bi,Sb)_2Te_3$ and Al to characterize the influence of these diffusion barriers on the transport properties of the JJs. We find four possible interlayers that allow for engineering a transparent S-TI interface. These results will enable us to perform Coulomb-blockade experiments with Al as a S.

[1] A.Y. Kitaev, Ann. Phys. 303, 2 (2003)

TT 19: Topological Superconductors

Time: Wednesday 11:45–13:00 Location: H23

TT 19.1 Wed 11:45 H23

Periodic supercurrent oscillations in topological insulator nanowire Josephson junctions in an axial magnetic field — •Michael Barth[1], Jacob Fuchs[1], Cosimo Gorini[1,2], and Klaus Richter[1] — [1]Institute of Theoretical Physics, University of Regensburg, D-93040 Regensburg, Germany — [2]Université Paris-Saclay, CEA, CNRS, SPEC, 91191, Gif-sur-Yvette, France

Helical surface states of 3-dimensional topological insulator (TI) nanowires are expected to have very promising physical properties like forbidden backscattering [1]. Moreover it is predicted that a topological superconducting state which could possibly host Majorana fermions can be realized by bringing a normal s-wave superconductor in close proximity to a TI [2]. We theoretically study the influence of an axial magnetic field on the supercurrent flow in TI nanowire Josephson junctions. The wire is modeled by an effective 2 dimensional setup and we take into account the special surface geometry by incorporating the partial superconducting coverage of the wire circumference. By employing numerical tight-binding simulations [3] and a semiclassical analytical approach [4], we show that the critical current can exhibit periodic oscillations, where the period corresponds to half of the superconducting flux quantum.

[1] X.-L. Qi and S.-C. Zhang, Rev. Mod. Phys. 83, 1057 (2011)
[2] A. Cook and M. Franz, Phys. Rev. B 84, 201105(R) (2011)
[3] Kun Zuoet et al., Phys. Rev. Lett. 119, 187704 (2017)
[4] V. P. Ostroukh et al., Phys. Rev. B 94, 094514 (2016)

TT 19.2 Wed 12:00 H23

Superconductivity in HgTe based quantum point contacts — •Johannes Baumann, Martin Stehno, Hartmut Buhmann, and Laurens Molenkamp — Institute for Topological Insulators and Physikalisches Institut, Experimentelle Physik 3, Universität Würzburg, 97074 Würzburg, Germany

Quantum point contacts have been suggested as tunable transmission elements in topological quantum circuits. We etched narrow constrictions into the weak links of topological Josephson junctions prepared from high-mobility, band-inverted HgTe quantum wells (2D topological insulator). In such devices, the conductance and supercurrent transmission decrease step-wise as we deplete the carriers in the constriction electrostatically with a gate. In the entire gating range, the supercurrent diffraction pattern in a perpendicular magnetic field exhibits a slow decay indicative of a small number of Andreev bound states funnelling through the constriction. Under microwave irradiation, odd Shapiro steps are suppressed in the current-voltage characteristic of the open constriction. This observation has been linked to the appearance of a 4pi-periodic contribution to the supercurrent of topological Josephson devices. Surprisingly, we recover all steps as we reduce the transmission to a small number of channels. We discuss possible origins of the effect and implications for topological quantum devices.

TT 19.3 Wed 12:15 H23

Tunable 4π-periodic supercurrent in HgTe-based topological nanowires — •Ralf Fischer[1], Jordi Picó-Cortés[2,3], Wolfgang Himmler[1], Gloria Platero[2], Milena Grifoni[3], Dimitry Kozlov[4], Nikolay Mikhailov[4], Sergey Dvoretsky[4], Christoph Strunk[1], and Dieter Weiss[1] — [1]Experimental and Applied Physics, University of Regensburg — [2]Instituto de Ciencia de Materiales de Madrid — [3]Institute of Theoretical Physics, University of Regensburg — [4]Novosibirsk, Russia

Topological insulator nanowires in proximity to conventional superconductors have been proposed as a tunable platform to realize topological superconductivity. The tuning is done using an axial magnetic flux Φ which allows transforming the system from trivial at $\Phi = 0$ to topologically nontrivial when half a magnetic flux quantum $\Phi = \Phi_0/2$ threads the cross-sectional area of the wire.

In our work, we investigate Josephson junctions based on HgTe nanowires and probe the Shapiro step spectrum. From the suppression of odd Shapiro steps, we extract the 4π- and 2π-periodic portion of the supercurrent $I_{4\pi}$ and $I_{2\pi}$ using a resistively and capacitively shunted junction model. The ratio $I_{4\pi}/I_{2\pi}$ changes from a small value of few percent at $\Phi = 0$ up to a maximum at $\Phi = \Phi_0/2$. The presence of $I_{4\pi}$ at $\Phi = 0$ and small magnetic fields indicate that in this regime Landau-Zener transitions cause the 4π-periodic current. By disentangling the 4π-periodic supercurrent of trivial an topological origin, our data suggest that topological 4π-periodic supercurrents dominate at axial magnetic fields above $\Phi_0/4$.

TT 19.4 Wed 12:30 H23

Complex magnetic ground states and topological electronic phases of atomic spin chains on superconductors — •Jannis Neuhaus-Steinmetz[1], Elena Vedmedenko[1], Thore Posske[2], and Roland Wiesendanger[1] — [1]Department of Physics, University of Hamburg, 20355 Hamburg, Germany — [2]I. Institute for Theoretical Physics, University of Hamburg, D-20355 Hamburg, Germany

Understanding the magnetic properties of atomic chains and nanoscopic wires on superconductors is an essential cornerstone on the road towards controlling and constructing topological matter. Yet, even in the simplest models of suspended chains, the classes of available magnetic ground states remain debated. Ferromagnetic (FM), antiferromagnetic (AFM), and spiral configurations have been suggested and experimentally detected, while additionally non-coplanar and complex collinear phases have been conjectured. Here, we resolve a recent controversy by determining the magnetic ground states of chains of magnetic atoms in proximity to a superconductor with Monte-Carlo methods, which employ the initial tight-binding model directly without further simplifications. We confirm the existence of FM, AFM and spiral ground states, and identify additional more complex ground states. We topologically classify the electronic structures, and investigate the stability of the magnetic states against increasing superconductivity. In addition, we introduce a computationally efficient alternative for approximating the magnetic ground state with an effective Heisenberg model, which we demonstrate by using our previous results as a benchmark for this new method.

TT 19.5 Wed 12:45 H23

Density functional Bogoliubov - de Gennes calculations for a topological superconductor — •Philipp Rüssmann[1,2] and Stefan Blügel[2] — [1]Institute of Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany

The possibility to combine topological electronic band structures and superconductivity (SC) opens new pathways towards engineering exotic quantum matter. Proximity induced superconductivity in the topological surface state of topological insulators (TIs) offers the possibility to realize a chiral p-wave superconductor. Such a superconductor is an exotic state of matter which supports non-Abelian anyons and is of great interest for Majorana-based quantum computing applications. Material-specific insights into the microscopic details of such SC/TI interfaces are of great interest and an indispensable ingredient in the challenging materials optimization problem.

Here we first introduce the recent Bogoliubov de-Gennes (BdG) extension to the all electron full potential relativistic Korringa-Kohn-Rostoker (KKR) Green function code JuKKR [1]. We apply the KKR-BdG method to the s-wave superconductor Nb [2] and investigate the proximity induced superconductivity in the topological surface state of a SC/TI heterostructure.

[1] https://jukkr.fz-juelich.de
[2] PRB **105**, 125143 (2022)

TT 20: Topology: Poster Session

In case the presenters cannot be present at their posters for the full duration of the poster session, they are kindly requested to leave a note at their poster indicating when they will be available for discussion.

Time: Wednesday 15:00–18:00 Location: P1

TT 20.1 Wed 15:00 P1

Effects of in-plane polarised light on graphene: Band gap, spin and topological quantum numbers — •Frederik Bartelmann[1], Marta Prada[2], and Daniela Pfannkuche[1,3] — [1]University of Hamburg, I. Institute of Theoretical Physics — [2]University of Hamburg, Institute of Nanostructure and Solid State Physics — [3]The Hamburg Centre for Ultrafast Imaging

If it were not for the effects of spin-orbit interaction, the band gap in graphene would close at the K-points, resulting in perfect Dirac cones. In this work, a graphene tight-binding band structure involving atomic s-, p- and d-orbitals is modified by irradiation with light. The light is polarised in-plane to affect the d_{xz}- and d_{yz}-orbitals, which are coupled via spin-orbit interaction, and the p_z-orbitals, which are predominant in the valence and conduction band. Floquet formalism is used to obtain dressed states and an altered band structure. The changes to valence and conduction band and thus the band gap are studied for a range of frequencies in the PHz regime. Along these studies, the correlation between real- and sublattice spin is probed as well as topological properties and how they behave under a change of frequency. Since the focus lies on the effects due to changes in the orbital composition of the dressed states, inter-band couplings are prioritised over intra-band ones. The goal of the studies is to gauge the effect of different irradiated frequencies on graphene and to evaluate possible applications of dressed states for topological quantum computers.

TT 20.2 Wed 15:00 P1

Static and dynamic magnetism 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

$(MnBi_2Te_4)(Bi_2Te_3)_n$ $(n = 0, 1)$ are van der Waals materials which exhibit a coexistence of topologically nontrivial surface states with intrinsic magnetism. 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 $MnBi_2Te_4$. Additionally, $MnBi_2Te_4$ exhibits a strongly anisotropic Mn spin relaxation in the paramagnetic state, which we explain by the sensitivity of the local electronic structure to the Mn spin orientation.

TT 20.3 Wed 15:00 P1

Low-dimensional spin correlations in $Mn_2P_2S_6$ and $MnNiP_2S_6$ as revealed by ESR spectroscopy — •Yurii Senyk[1], Joyal John Abraham[1,2], Alexey Alfonsov[1], Yuliia Shemerliuk[1], Sebastian Selter[1,2], Saicharan Aswartham[1], Bernd Büchner[1,3], and Vladislav Kataev[1] — [1]Leibniz IFW Dresden, D-01069 — [2]Institute for Solid State and Materials Physics, TU Dresden, D-01069 — [3]Institute for Solid State and Materials Physics and Wurzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, D-01062

$Mn_2P_2S_6$ and $MnNiP_2S_6$ are members of the transition metal phosphorus trichalcogenide family which belongs to the layered van der Waals (vdW) materials class. Such compounds are considered to be attractive for designing novel spintronic devices due to their remarkable structural and magnetic properties. Here we report the electron spin resonance studies on single crystals of $Mn_2P_2S_6$ and $MnNiP_2S_6$

using an X-band (9.56 GHz) spectrometer. Measurements were done in a wide temperature range and at various angles between the applied magnetic field and crystal axes. The obtained spectra can be well fitted to the Lorentzian lineshape enabling an accurate determination of the linewidth and the resonance field. Remarkably, the angular temperature dependences of the linewidth show signatures of the low-dimensional spin-spin correlations in the pure Mn compound whereas the mixed compound demonstrates a rather three-dimensional behaviour.

TT 20.4 Wed 15:00 P1

Quantum anomalous hall devices on magnetically doped topological insulator films — •Roozbeh Yazdanpanah Ravari[1], Gertjan Lippertz[1,2], Anjana Uday[1], Andrea Bliesener[1], Alexey Taskin[1], and Yoichi Ando[1] — [1]University of Cologne, Cologne, Germany — [2]KU Leuven, Leuven, Belgium

Magnetic doping opens an exchange gap in the surface states of topological insulators (TIs) at the Dirac point by breaking time reversal symmetry. Such systems manifest the quantum anomalous Hall (QAH) effect which is characterized by quantized Hall resistance and zero longitudinal resistance. To explore this phenomena, devices are fabricated on thin films of V-doped $(Bi_{1-x}Sb_x)_2Te_3$. This contribution highlights our effort to better understand this effect, including a study of the QAH breakdown where in high current densities or small dimensions, the quantized state is lost. Another ongoing effort focuses on interfacing the quantum anomalous hall insulator (QAHI) system with a superconductor (SC) through devices with different geometries, where the obtained results suggest high transparency of the QAH/SC interface.

TT 20.5 Wed 15:00 P1

Entanglement spectrum of Su-Schrieffer-Heeger model — •Mahsa Alsadat Seyed Heydari[1] and Jahanfar Abouei[2] — [1]University of Konstanz, Germany — [2]Institute for Advanced Studies in Basic Sciences (IASBS), Iran

We investigate the ground state properties of a one dimensional topological insulator, the Su-Schrieffer-Heeger (SSH) chain in the absence/presence of an alternative spin-orbit coupling (SOC), employing single-particle entanglement spectrum (ES). In the presence of SOC, owing to the spin-flip processes, different topologically trivial and nontrivial phases appear in the ground state phase diagram of the model. Using the matrix of single-particle correlation functions, we obtain the single-particle ES as well as the entanglement entropy, and show that they behave differently in these phases. We introduce an indicator, called entanglement gap, defined as the difference between the lowest positive entanglement level and the highest negative level, and demonstrate that this indicator distinguishes the topological phases from the trivial phase of the model.

TT 20.6 Wed 15:00 P1

Current increase by weakening site-site interaction in SSH lattices — •Mirko Rossini, Brecht Donvil, and Joachim Ankerhold — Institute for Complex Quantum Systems and IQST, Ulm University, Germany

One of the simplest models supporting topologically protected states is the well-known Su-Schrieffer-Heeger (SSH) model. As a 1D chain with staggered NN hopping amplitudes, it can host two protected 0-energy modes when the distribution of hopping amplitudes is properly adjusted. These edge states are energetically relatively stable against ambient noise. thus providing natural protection from any excitation living on an edge of the chain.

In this poster, we show the realization of a current through such a chain, which in the topological regime could provide a naturally protected channel for the safe transport of excitations in space. The current is created by terminating the SSH chain at particle reservoirs. It has been shown that the edge-to-edge transport of particles in such a system is exponentially suppressed with respect to the length of the chain, preventing the practical use of this model for the stated purposes. Therefore we propose, after a brief introduction to the main properties of the SSH model, an extended model for the 1D lattice that, by weakening a small selection of hopping parameters along the chain, is able to increase the current through the edges while preserving some of the topological protection offered by the original SSH model.

TT 20.7 Wed 15:00 P1

Search for new europium-based intermetallic 122 materials with non-trivial topological properties — •Sarah Krebber, Kristin Kliemt, Cornelius Krellner, and Asmaa El Mard — Max-von-Laue Straße 1, 60438 Frankfurt am Main, Physikalisches Institut

Today, more and more Eu-based compounds come into focus of magnetic topological nontrivial materials. The first examples were thin films of EuS on Bi_2Se_3 [1]. In recent studies, the material $EuCd_2As_2$ has attracted a lot of attention due to emergence of a variety of topological phases and magnetic phenomena [2,3]. Recently, a spin fluctuation induced Weyl semimetal state in the paramagnetic phase of $EuCd_2As_2$ [2] and its tunability by pressure [4] was discovered. Furthermore, the similar material $EuCd_2P_2$ has been explored due to its strong colossal magnetoresistance effect [5]. In this work we present the single crystal growth and characterization of the related system EuT_2X_2, with T = Cd, Zn, Mn and X = P, crystallizing in the same trigonal structure (P-3m1) in order to search for similar effects in these materials. The physical properties of the compounds are explored via magnetization, electrical transport and heat capacity.

[1] Katmis et al., Nature 533, 513 (2016)
[2] Ma et al., Science Adv. 5, eaaw4718 (2019)
[3] Jo et al., Phys. Rev. B 101, 140402(R) (2020)
[4] Gati et al., Phys. Rev. B 104, 155124 (2021)
[5] Wang et al., Adv.Mater. 33, 2005755 (2021)

TT 20.8 Wed 15:00 P1

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

De Haas-van Alphen (dHvA) measurements at low temperatures and fields up to 18 T provided insight into the band structure of the topological semimetal PdGa which is presented in this poster. Previous investigation of PtGa revealed the topological character [1] of this sister compound of PdGa. Hence, angle-resolved measurements of the dHvA effect were performed on PdGa and showed a good agreement with the calculated band structure. This revealed a multitude of Fermi surfaces and eight spin-splitted bands crossing the Fermi energy. In particular, the calculations show a similar band structure as for PtGa, including two topologically protected multifold degenerate band-touching nodes. Furthermore, we analyzed the temperature dependence of the dHvA oscillations to determine the effective masses for field aligned along the crystallographic [100] axis. The low masses also show a good agreement to the calculations and, therefore, indicate insignificant correlations of the electrons.

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

TT 20.9 Wed 15:00 P1

Current phase relation of HgTe nanowire Josephson junctions in an axial magnetic field — •N. Hüttner[1], W. Himmler[1], D. A. Kozlov[2], N. N. Mikhailov[2], S. A. Dvoretsky[2], D. Weiss[1], and C. Strunk[1] — [1]Experimental and Applied Physics, University of Regensburg, D-93040 Regensburg, Germany — [2]Novosibirsk, Russia

Topological insulators (TIs) such as HgTe nanowires host topological surface states. Their band structure can be tuned to a Dirac shape via the application of an axial magnetic field ($B_\parallel$) [1]. For proximitized nanowires this is expected to tune between trivial and topological supercurrents as recent experiments suggest [2]. Here we directly probe the current phase relation (CPR) of a tunable TI Josephson junction. The TI junction consists of a HgTe nanowire proximitized by superconducting Nb contacts embedded into an asymmetric DC-SQUID together with an Al/AlOx/Al junction. Beeing in the short junction regime [2], the TI junction features a strongly anharmonic CPR [3,4] with a high average transparency of $D \approx 0.95$ for $n \approx 9 \pm 2$ channels [4]. Varying $B_\parallel$ controls the magnetic flux enclosed by the nanowire surface. In the range $0 - 1.5\Phi_0$ we observe a strong modulation of the critical current and interference of phase shifted contributions of individual channels creating a great variety of CPR shapes.

[1] A. Cook *et al.*, Phys. Rev. B **84**, 201105 (2011).
[2] R. Fischer *et al.*, Phys. Rev. Res. **4**, 013087 (2022).
[3] A. A. Golubov *et al.*, Rev. Mod. Phys. **76**, 411 (2004).
[4] C. Baumgartner *et al.*, Phys. Rev. Lett. **126**, 037001 (2021).

TT 20.10 Wed 15:00 P1

Ground-state splitting of parafermions zero modes at a fi-

nite distance — •Raphael L R C Teixeira[1,2], Amal Mathew[2,3], Roshni Singh[2,3], Solofo Groenedijk[2], Andreas Haller[2], Edvin G Idrisov[2], Luis G G V Dias da Silva[1], and Thomas L Schmidt[2] — [1]Instituto de Fisica - Universidade de Sao Paulo, Sao Paulo Brazil — [2]Department of Physics and Materials Science Université du Luxembourg, Luxembourg, Luxembourg — [3]Indian Institute of Technology, Bombay, India

Parafermion bound states can be regarded as fractional excitations that generalize Majorana bound states. Parafermions appear in strongly-correlated systems, and in particular, fractional Quantum Hall (FQH) edge states with induced superconductivity can be used to create localized $\mathbb{Z}_{2n}$ parafermion modes. Previous works have used the single-instanton approximation to calculate the ground-state energy splitting in the limit of a large distance between the parafermions. In this work, we go beyond this approximation to determine the energy splitting in shorter systems, paving the way to better understanding experimentally relevant systems. We discuss the implications of a finite length in the coupling between parafermions and how it goes beyond the corresponding effect for Majorana bound states.We The analytical results agreed with Monte Carlo simulations implying the corrections we found cannot be neglected.

TT 20.11 Wed 15:00 P1

Full counting statistics of electron transport through a Majorana single-charge transistor — •Eric Kleinherbers, Alexander Schünemann, and Jürgen König — Faculty of Physics and CENIDE, University Duisburg-Essen, 47057 Duisburg, Germany

We study full counting statistics of electron transport through a Majorana single-charge transistor (MSCT) [1]. The MSCT can host both Majorana bound states and Cooper pairs. In addition, the system is coupled to a superconducting and a metallic lead. A current through the system is realized by means of the Josephson-Majorana cycle [2], where sequential tunneling (normal and anomalous) of two electrons into the system is followed by the transfer of a Cooper pair into the superconductor. We find a highly correlated electron transfer which can be indicated by a sign violation of factorial cumulants. Moreover, when the superconductor is only weakly coupled to the MSCT, we find for large bias voltages a strong suppression of the electron current. This effect is explained by the excitation of a dark state that effectively decouples from the leads.

[1] A. Zazunov et al., Phys. Rev. B 84, 165440 (2011)
[2] N. Didier et al., Phys. Rev. B 88, 024512 (2013)

TT 21: Correlated Electrons: Poster Session

In case the presenters cannot be present at their posters for the full duration of the poster session, they are kindly requested to leave a note at their poster indicating when they will be available for discussion.

Time: Wednesday 15:00–18:00 Location: P1

TT 21.1 Wed 15:00 P1

Single crystal growth and characterization of $CeCoIn_5$ and $GdCoIn_5$ — •Leonard Essich, Anja Philipp, Alexej Kraiker, Kristin Kliemt, and Cornelius Krellner — Physikalisches Institut, Goethe Universität Frankfurt, 60438 Frankfurt am Main

The family of 115 rare-earth compounds $RTIn_5$ (T = Co, Rh, Ir) with tetragonal crystal structure received growing attention over the past decades. Low-temperature phenomenologies associated with the strong correlations of the 4f-electrons of the rare-earth element and the quasi-two-dimensionality of the Fermi surface such as spin and valence fluctuations [1], heavy fermions [2], and anisotropic superconductivity [3] are observed for the Ce-based compounds. The $GdTIn_5$ series show magnetic ordering of local 4f-moments with a reduced interplane coupling for $GdCoIn_5$ [3].

In this contribution, we show our results of the self-flux growth of $CeCoIn_5$ and $GdCoIn_5$ single crystals. The crystallographic orientation was determined using microscopy and Laue X-ray diffraction along with the characterization by powder X-ray diffraction, magnetization, specific-heat and specific-resistivity measurements for both compounds.

[1] D. Betancourth et al., JMMM **375**, 744 (2015)
[2] Y. Onuki et al., J. Phys. Soc. Jpn. **71**, 162 (2002)
[3] J.I. Facio et al., PRB **91**, 014409 (2015)

TT 21.2 Wed 15:00 P1

Single crystal growth and characterization of $Eu(Pd_{1-x}Au_x)_2Si_2$ — •Robert Möller, Marius Peters, Cornelius Krellner, and Kristin Kliemt — Physikalisches Institut, Goethe-Universität Frankfurt, Germany

In a general phase diagram for Eu compounds [1], the intermediate valent $EuPd_2Si_2$, T_V ~ 150 K, is located very close, but slightly at the high-pressure side of a second order critical endpoint [2]. The analysis of polycrystalline samples of $Eu(Pd_{1-x}Au_x)_2Si_2$ revealed that in this series a critical endpoint can be found which separates the region of continuous from first order transitions. It was shown that the valence state of the material can be tuned via Au substitution and that for x between 0.05 and 0.2 the transition becomes a first order phase transition [3]. In this contribution, we present the Czochralski growth and the characterization of $Eu(Pd_{1-x}Au_x)_2Si_2$ single crystals. Using magnetization and heat capacity measurements, we study the changes in the nature of the phase transition in detail.

[1] Y. Onuki et al., Philosophical Magazine 97, 3399 (2017)
[2] B. Batlogg et al., in: Wachter, Boppart (eds.): Valence Instabilities, North-Holland publishing company (1982)
[3] C. U. Segre et al., Physical Review Letters 49, 1947 (1982)

TT 21.3 Wed 15:00 P1

Single crystal growth of $EuPd_2Si_2$ under enhanced gas pressure — •Alexej Kraiker, Marius Peters, Kristin Kliemt, and Cornelius Krellner — Physikalisches Institut, Goethe Universität Frankfurt, 60438 Frankfurt am Main, Germany

The study of collective phenomena raising from enhanced coupling between electrons and phonons is focussed on materials exhibiting phase transitions involving both, electronic and lattice-degrees of freedom. One system providing such a strongly coupled phase transition is $EuPd_2Si_2$ crystallizing in the $ThCr_2Si_2$ structure type. Because of the the high vapor pressure of Eu, high-quality single crystals of EuT_2X_2-compounds are very challenging to grow in larger size. One way to prevent Eu from evaporating out of the melt, is growing the crystals in argon overpressure. In this contribution, we present the crystal growth of $EuPd_2Si_2$ single crystals with a 20 bar Czochralski-furnace as well as the commissioning of a 150 bar high-pressure furnace which will provide the possibility of both the growth by the Czochralski and the Bridgman method.

TT 21.4 Wed 15:00 P1

$YbIn_{1-x}Ag_xCu_4$: single crystal growth and characterisation — •Michelle Ocker, Bereket Ghebretinsae, Kristin Kliemt und Cornelius Krellner — Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt/Main, Germany

The compound $YbInCu_4$ undergoes a 1^{st} order valence transition at T_v =42 K by changing the temperature. Thus, ytterbium in the compound is present in the $Yb^{2.9+}$ state at high temperatures and as $Yb^{2.7+}$ at low temperatures [1]. In analogy to Eu compounds, the first order valence transition is suspected to end in a second order critical endpoint [2]. In order to study this valence transition in more detail, single crystal samples can be prepared in In-Cu flux which are substituted with silver [3]. With increasing Ag content, negative chemical pressure within the crystal is increased and the characteristics of the valence transition changes significantly. Here, we report on the single crystal growth with different Ag substitution levels and the results of our structural, chemical and physical characterization.

[1] H.Sato et al., Physica B 351, (2004) 298
[2] Y. Ōnuki et al., J. Phys. Soc. Jpn. 89, (2020) 102001
[3] J. L. Sarrao et al., Phys. Rev. B 54, (1996) 12207

TT 21.5 Wed 15:00 P1

Elastoresistance of $Eu_2T_2P_2$ (T=Fe, Ru, Co) systems close to a collapsed tetragonal phase transition — •Teslin Rose Thomas[1], N. S. Sangeetha[1], Thanh Duc Nguyen[2], Julian Reusch[2], Marius Peters[2], Kristin Kliemt[2], Cornelius

Krellner[2], and Anna E. Böhmer[1] — [1]Lehrstuhl für Experimentalphysik IV, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum — [2]Physikalisches Institut, Goethe-Universität Frankfurt, Max-von-Laue-Straße 1, 60438 Frankfurt am Main

Manipulation of the properties of materials by applying anisotropic strain is an increasingly common method used in the study of correlated electron materials. In particular, the nematic state of several unconventional superconductors has been studied intensively using elastoresistance as a probing tool. In the current project, we employ elastoresistance to study the state close to the uncollapsed to collapsed-tetragonal transitions in $Eu_2T_2P_2$ (T=Fe, Ru, Co) and $CaCo_2As_2$ 122 systems. In contrast to investigations of nematicity, where the response to uniaxial strain is studied, we apply bi-axial strain which is by symmetry well suited. The corresponding elastoresistance is compared for the different compounds and at different temperatures. The results are then compared with the temperature and pressure dependence of lattice constants, which show the tetragonal collapse.

We acknowledge support from the German Research Foundation (DFG) under CRC/TRR 288 (Project A02).

TT 21.6 Wed 15:00 P1

Valence fluctuations and structural collapse in Eu-based phosphides EuT_2P_2 — Marius Peters[1], •Kristin Kliemt[1], Julian Dominik Reusch[1], Thanh Duc Nguyen[1], Franziska Walther[1], Michael Merz[2], Gaston Garbarino[3], Sofia Michaela Souliou[2], Matthieu Le Tacon[2], Amir-Abbas Haghighirad[2], and Cornelius Krellner[1] — [1]Kristall- und Materiallabor, Physikalisches Institut, Goethe University Frankfurt, Max-von-Laue-Str. 1, D-60438 Frankfurt — [2]Karlsruhe Institute of Technology, Institute for Quantum Materials and Technology, D-76021 Karlsruhe — [3]European Synchrotron Radiation Facility (ESRF), F-38043 Grenoble

Studies of enhanced coupling between electrons and phonons is focussed on materials exhibiting phase transitions involving both electronic and lattice degrees of freedom. Europium in intermetallic systems can exhibit different magnetic ground states: If the ground state is Eu^{2+}, the system shows long range magnetic order; if the ground state is Eu^{3+}, no magnetic order is observed. Instead, valence fluctuations occur in intermediate valent states [1].

In this work, we report on the structural collapse in divalent europium systems EuT_2P_2 (T = Fe, Co, Ru), which is connected to a change of europium's ground state by using single crystal diffractometry at pressures up to 15 GPa at 15 K and 300 K. Additionally, we show characterizations of the electronic and structural contributions to valence fluctuations in $EuNi_2P_2$.

[1] Y. Onuki et al., Philos. Mag. 97, 3399 (2017).

TT 21.7 Wed 15:00 P1

Crystal growth and characterization of $LnCo_2P_2$ (Ln = Pr, Nd) — •Fabian Fiedler, Marius Peters, Kristin Kliemt, and Cornelius Krellner — Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt/Main, Germany

In condensed matter systems, the 4f-driven temperature scales at the surfaces of correlated materials have increasingly come into the focus of research efforts. Here, we present the crystal growth of $LnCo_2P_2$ (Ln = Pr, Nd) in tin flux and the corresponding structural/physical characterization.

Using temperatures of up to 1400°C and a vertical temperature-gradient, we optimized the growth, resulting in large high-quality single crystals, allowing for physical characterization, especially by means of thermodynamic measurements and angle-resolved photoemission spectroscopy.

The structural and chemical characterization is performed by X-ray powder diffractometry, energy-dispersive X-ray spectroscopy and the Laue-method.

Magnetic properties of these systems, arising from the combination of the 4f-moments of Ln^{3+}-ions and the 3d-moments of Co^{3+}, are investigated by measurements of magnetization, heat capacity and resistivity.

TT 21.8 Wed 15:00 P1

Growth and characterization of $KFe_{1-x}Ag_{1+y}Ch_2$ — •Jutta Püttmann, N. S. Sangeetha, Andreas Kreyssig, and Anna E. Böhmer — Experimentalphysik IV, Universitätstraße 150, 44801 Bochum

Iron-based 122-compounds with $ThCr_2Si_2$ structure have been intensely studied over the past decades. K-based chalcogenides, such as $K_xFe_{2-\delta}Se_2$ have attracted attention due to their high-temperature superconductivity, their strong electronic correlations, and their complex microstructure dominated by vacancies and phase separation. Recently, $KFe_{0.8}Ag_{1.2}Te_2$ has been found to provide the possibility to study an iron chalcogenide 122-systems without vacancies on the alkali site and to investigate a superstructure in the Fe/Ag plane with an interesting magnetic and nematic ordering [1, 2].

The growth of K-based single crystals is challenging due to the high vapor pressure and reactivity of potassium. We developed a new, affordable and efficient growth technique using containers made from high-temperature resistant stainless steel that can be sealed without any air-exposure of the starting materials. The growth of $KFe_{1-x}Ag_{1+y}Ch_2$-crystals by self-flux was optimized with respect to the starting material composition. The obtained crystals were characterized by EDX and XRD. The XRD patterns were analyzed for signs of superstructure in the Fe/Ag plane. Additionally, low-temperature measurements were carried out to confirm the magnetic transitions.

[1] Yu Song et al., Phys. Rev. Lett. 122, 087201 (2019)
[2] Yu Song et al. Phys. Rev. Lett. 123, 247205 (2019)

TT 21.9 Wed 15:00 P1

Classical Ising-like dipolar antiferromagnet $DyScO_3$ with slow spin dynamics — •Nikita Andriushin[1], Stanislav Nikitin[2,3], and Andrey Podlesnyak[4] — [1]TU Dresden, Germany — [2]MPI CPfS, Dresden, Germany — [3]PSI, Villigen, Switzerland — [4]ORNL, Tennessee, USA

The usual timescale of the spin flip process in common magnetic systems is femto- to picoseconds. In this work we show with the help of both AC and DC magnetization measurements and classical Monte-Carlo calculations that the spin dynamics in $DyScO_3$ can be slowed down to milliseconds and further. The orthorhombic $DyScO_3$ has a large uniaxial anisotropy caused by the strong crystalline electric field (CFT), which freezes magnetic moments below a certain temperature. Large anisotropy and long-range dipolar interaction result in an Ising-like antiferromagnetic ordering with critical temperature $T_C = 3.14$ K. Magnetization and susceptibility measurements revealed a magnetization relaxation on a timescale of minutes, which is unexpected for an antiferromagnet. As a classical approach for modeling Ising-like spin systems, the Monte-Carlo calculations with Metropolis algorithm were used. Our calculations, taking into account the dipole-dipole interaction energy, comprehensively reproduce the observed magnetic behavior, correctly predict the ground state, critical temperature and capture slow magnetization dynamics.

TT 21.10 Wed 15:00 P1

Hierarchical equations of motion approach to open quantum dynamics: Matrix product state formulation in twin space — •Yaling ke[1], Raffaele Borrelli[2], and Michael Thoss[1] — [1]Institute of Physics, Albert-Ludwig University Freiburg, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany — [2]DISAFA, Università di Torino, I-10095 Grugliasco, Italy

The hierarchical equations of motion (HEOM) is a numerically exact approach to studying open quantum dynamics with strong non-perturbative and non-Markovian system-environment interactions at finite temperatures. Although considerable progress has been made over the past few decades to extend the applicability of the HEOM approach, the numerical cost is still very expensive for reasonably large systems.

In this contribution, we present the twin-space formulation of the HEOM approach in combination with the matrix product state representation for an open quantum system coupled to a hybrid fermionic and bosonic environment. The key ideas are a reformulation of a set of differential equations for the auxiliary density matrices into a time-dependent Schroedinger-like equation for an augmented multi-dimensional wave function as well as its tensor decomposition into a product of low-rank matrices. The new approach facilitates accurate simulations of non-equilibrium quantum dynamics in larger and more complex open quantum systems with both factorized and correlated initial condition.

TT 21.11 Wed 15:00 P1

Quantum criticality of $2k_F$ density wave order in two-dimensional metals — •Lukas Debbeler and Walter Metzner — Max Planck Institute for Solid State Research

We analyze the quantum critical point at the transition towards incommensurate charge or spin density wave order with a $2k_F$ wave vector that connects a single pair of hot spots on the Fermi surface. Perturbative renormalization group (RG) calculations confirm non-Fermi liquid behavior with anomalous frequency scaling and renormalization of the Fermi surface in proximity to the hot spots. Employing a functional RG approach we treat frequency and momentum dependence as well as fermionic and bosonic degrees of freedom on equal footing. This approach does not lead to a self consistent solution with a peak of the static polarization function at the $2k_F$-vector. We explore the possibility of a self consistent quantum critical solution via a scaling ansatz.

TT 21.12 Wed 15:00 P1

Field dependence of the low-energy magnon modes and a spin-cholesteric phase in $Sr_3Fe_2O_7$ — •Nikolai Pavlovskii[1], Yuliia Tymoshenko[1], Darren C. Peets[1], Alexandre Ivanov[2], Jacques Ollivier[2], Bernhard Keimer[3], and Dmytro Inosov[1] — [1]TU Dresden, Germany — [2]ILL, Grenoble, France — [3]MPI for Solid State Research, Stuttgart, Germany

We systematically studied low-energy magnon excitations in the helimagnetically ordered bilayer perovskite $Sr_3Fe_2O_7$. The magnetic ground state was previously believed to be characterized with a single-q magnetic order parameter that results from a frustration of exchange interactions, resulting in two types of equivalent helimagnetic domains. Our present results suggest that it could be instead a double-q state. Our elastic neutron-scattering measurements in a magnetic field applied along one of the (110) crystal directions further reveal an additional phase transition within the magnetic phase, associated with the destruction of long-range order along the direction orthogonal to the field, leading to an unusual spin-cholesteric magnetic phase that breaks both chiral symmetry and translational symmetry along only one of the crystal directions. In the orthogonal direction, we observe only short-range quasielastic spin dynamics. Across the transition from the magnetically ordered to the spin-cholesteric phase, these slow spin fluctuations fill in the spin gap in the spin-wave spectrum, as we can see in the high-resolution inelastic neutron-scattering spectra, and ultimately dominate the low-energy magnetic excitation spectrum after the long-range magnetic order is destroyed.

TT 21.13 Wed 15:00 P1

Crystal Growth and Characterization of $ZrFe_4Si_2$ — •Katharina M. Zoch, Isabel Reiser, Alexander Bodach, Kristin Kliemt, and Cornelius Krellner — Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt am Main, Germany

The $ZrFe_4Si_2$-structure consists of edge-linked Fe-tetrahedra along the crystallographic c-direction. This type of arrangement is prone to show frustration and low dimensional fluctuations. First results on polycrystalline samples indicate that $ZrFe_4Si_2$ displays some sort of weak magnetic order, for an Fe-based compound, unusual low temperatures as well as deviant behavior in specific heat and resistivity compared to normal metals [1,2]. To investigate these features further, we are in need of single crystals. The crystal growth is a challenging subject. The compound is strongly peritectic melting and its elements are reactive with common crucible materials. Crystal growth experiments utilizing the Czochralski methods were performed, and the structure as well as magnetic, thermodynamic and electrical transport properties of the material were analyzed.

[1] M. O. Ajeesh et al., Phys. Rev. B, **102**, 184403 (2020)
[2] K. Weber, PhD thesis Technische Universität Dresden (2017)

TT 21.14 Wed 15:00 P1

Magnetic properties of monocrystalline euchroite $Cu_2(AsO_4)(OH)_3(H_2O)$ — •Yannis Hilgers, Leonie Heinze, Dirk Menzel, and Stefan Süllow — IPKM, TU Braunschweig, Braunschweig, Germany

Previous studies of magnetic susceptibility and magnetisation on a natural polycrystalline sample of euchroite ($Cu_2(AsO_4)(OH)_3(H_2O)$) suggested that euchroite may be understood as a representation of a delta spin chain and exhibits a spin gap of about 50 K. In order to test this notion, we have performed a corresponding study on a monocrystalline sample, determining these properties along the three crystallographic axes. Magnetic susceptibility from 2 K to 300 K and magnetisation for magnetic fields up to 5 T were measured on a natural monocrystalline sample, previously characterized for crystallinity by Laue diffraction, of euchroite. From our data, we establish Curie-Weiss temperatures $\Theta_{CW,a} = -150(20)$ K, $\Theta_{CW,b} = -140(10)$ K, $\Theta_{CW,c} = -140(10)$ K, significantly larger in value than $\Theta_{CW} = -50$ K by Kikuchi et al. Moreover, we find that at low temperatures, magnetic susceptibility exhibits a spin gap, and a residual magnetisation at low temperatures can be understood in terms of about 1 % free magnetic impurity (S = 1/2) moments. Fitting a Brillouin-function to the magnetisation data with S = 1/2 results in saturation magnetisations of $M_{s,a} = 89{,}2(2{,}1)$ emu mol^{-1}, $M_{s,b} = 94{,}0(1{,}7)$ emu mol^{-1}, $M_{s,c} = 108{,}2(5{,}8)$ emu mol^{-1}. From this, the minimal length l_{min} of the delta spin chain segments can be estimated to $l_{min} = 350(50)$ Å. Altogether, our data are consistent with euchroite as a delta spin chain material with a spin gap of about 50 K.

TT 21.15 Wed 15:00 P1

Bond-directional nearest-neighbor excitations in the proximate Kitaev spin liquid Na_2IrO_3 probed by RIXS — •Marco Magnaterra[1], Alessandro Revelli[1], Karolin Hopfer[1], Christoph Sahle[2], Marco Moretti Sala[3], Giulio Monaco[4], Jan Attig[5], Ciarán Hickey[5], Anton Jesche[6], Philipp Gegenwart[6], Simon Trebst[5], Paul H. M. van Loosdrecht[1], Jeroen van den Brink[7], and Markus Grüninger[1] — [1]II. Physikal. Inst., Universität zu Köln — [2]ESRF, Grenoble, France — [3]Dip. di Fisica, Politecnico di Milano, Italy — [4]Dip. di Fisica, Università di Padova, Italy — [5]Inst. für Theo. Physik, Universität zu Köln — [6]Exp. Physics VI, University of Augsburg — [7]Inst. for Theo. Solid State Physics, IFW Dresden

The Kitaev model hosts a spin-liquid ground state with Majorana fermion excitations. It is based on bond-directional exchange, i.e. Ising-like interactions that couple different spin components on different bonds. In Na_2IrO_3, resonant inelastic x-ray scattering (RIXS) revealed fingerprints of Kitaev physics in the magnetic excitations [1]. In fact, the RIXS intensity shows a sinusoidal **q** dependence that proves the nearest-neighbor or single-bond character of the excitations. We report on refined RIXS measurements where we exploit the polarization dependence of the different spin channels and the **q** dependence of the different bonds to demonstrate the direct connection between spin component and bond direction. Our results establish the bond-directional nearest-neighbor character of magnetic excitations in Na_2IrO_3.

[1] A. Revelli *et al.*, Phys. Rev. Research 2, 043094 (2020).

TT 21.16 Wed 15:00 P1

Asymmetric melting of the 1/3-plateau for the Kagome lattice antiferromagnet — •Henrik Schlüter[1], Jürgen Schnack[1], and Johannes Richter[2] — [1]Bielefeld University, Germany — [2]University of Magdeburg and MPIPKS Dresden, Germany

The kagome lattice Heisenberg antiferromagnet (KHAF) is a rich source of unconventional physics not only regarding its spin-liquid ground state but also with respect to its behavior at non-zero field and temperature.

Here we investigate the phenomenon of the asymmetric melting of the magnetization plateau at 1/3 of the saturation magnetization, see Refs. [1, 2]. We explain the effect by discussing the energy diagram and the density of states constructed from finite-temperature Lanczos data for KHAF with up to 48 sites [3].

[1] J. Schnack, J. Schulenburg, J. Richter, Phys. Rev. B **98**, 094423 (2018)
[2] T. Misawa, Y. Motoyama, Y. Yamaji, Phys. Rev. B **102**, 094419 (2020)
[3] H. Schlüter, F. Gayk, H.-J. Schmidt, A. Honecker, J. Schnack, Z. Naturforsch. A **76**, 823 (2021)

TT 21.17 Wed 15:00 P1

Berry Phases of Vison Transport in $\mathbb{Z}_2$ Topological Ordered States from Exact Fermion-Flux Lattice Dualities — Chuan Chen[1,2], •Peng Rao[2], and Sodemann Inti[2,3] — [1]Institute for Advanced Study, Tsinghua University, 100084 Beijing, China — [2]Max-Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [3]Institut für Theoretische Physik, Universität Leipzig, 04103 Leipzig, Germany

We develop an exact map of all states and operators from 2D lattices of spins-1/2 into lattices of fermions and bosons with mutual semionic statistical interaction that goes beyond previous dualities of $\mathbb{Z}_2$ lattice gauge theories because it does not rely on imposing local conservation laws and captures the motion of 'charges' and 'fluxes' on equal footing. This map allows to explicitly compute the Berry phases for the transport of fluxes in symmetry enriched topologically ordered states that can be either chiral, non-chiral, abelian or non-abelian, and whose numerical complexity reduces to diagonalizing free-fermion Hamiltonians. Among other results, we establish numerically the conditions under which the Majorana-carrying flux excitation in Ising-

Topologically-Ordered states enriched by translations acquires 0 or π phase when moving around a single plaquette.

TT 21.18 Wed 15:00 P1

Linked cluster expansions for a perturbed topological phase — •Viktor Kott, Matthias Mühlhauser, and Kai Phillip Schmidt — Friedrich-Alexander-Universität, Erlangen-Nürnberg, Germany

We investigate the robustness of Kitaev's toric code in a uniform magnetic field on several two-dimensional lattices by perturbative linked cluster expansions using a full graph decomposition. In particular, the full graph decomposition allows to correctly take into account the non-trivial mutual exchange statistics of the anyonic elementary excitations. This allows us to calculate the ground-state energy and excitation energies of the topological phase which are then used to study the quantum phase transitions out of the topologically ordered phase as a function of the field direction.

TT 21.19 Wed 15:00 P1

Linked-cluster expansions for Rydberg atom arrays on the Kagome lattice — •Antonia Duft, Matthias Mühlhauser, Patrick Adelhardt, and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Deutschland

We investigate a model of hardcore bosons on the links of a Kagome lattice subject to a long-range decaying van-der-Waals interaction. This model is known to be the relevant microscopic description of Rydberg atom arrays excited by a detuned laser field which has been realized in experiments recently. We apply high-order linked cluster expansions about different limits to investigate the quantum phase diagram. One particular interest is to find further evidence for the proposed topological phase in this quantum platform.

TT 21.20 Wed 15:00 P1

Fractal quantum criticality in the Newman-Moore model in a transverse field investigated by linked cluster expansions — •Raymond Wiedmann, Matthias Mühlhauser, and Kai Phillip Schmidt — Friedrich-Alexander-Universität, Erlangen-Nürnberg, Germany

The zero-temperature phase transition in the two-dimensional self-dual quantum Newman-Moore model is investigated using perturbative linked cluster expansions. The model exhibits type-II fracton excitations that have a highly restricted mobility on the lattice. High-order series expansions of the energy gap for different quasi-particle sectors as well as the vacuum energy are calculated using perturbative continuous unitary transformations and matrix perturbation theory, respectively. Our results indicate a first-order phase transition between the fractal phase and the polarized phase at the self-dual point in the model.

TT 21.21 Wed 15:00 P1

Improved EPR spectroscopy on single molecular magnets — •Michael Schulze[1], Daniel Schroller[1], Gheorghe Taran[1], Eufemio Pineda[3], Mario Ruben[2], Christoph Sürgers[1], and Wolfgang Wernsdorfer[1] — [1]Physikalisches Institut, KIT, Karlsruhe — [2]Institut für Nanotechnologie, KIT, Karlsruhe — [3]Departamento de Química, Universidad de Panamá, Panama City

The quantum nature and large magnetic anisotropies in lanthanide-based single molecular magnets (SMMs) provides potential for interesting applications in quantum computing and information storage. The development of the micro-SQUID technique provides a tool for high-resolution magnetization measurements of SMM single crystals from the mK-range up to several Kelvin. EPR spectroscopy, where different spin states are excited by resonant absorption of radiofrequency radiation, serves as a powerful extension of the micro-SQUID technique to gain further insight into the magnetic properties of SMMs. This project strives to improve various features of this combined setup, such as higher coupling strengths, better thermalization, and coherent spin manipulation of SMMs.

TT 21.22 Wed 15:00 P1

Electrical read out of the nuclear spin and implementation of quantum algorithms on Tb_2Pc_3 triple decker — •Luca Kosche[1], Franck Balestro[2], Mario Ruben[3,4,5], and Wolfgang Wernsdorfer[1,2,3,4] — [1]Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe — [2]CNRS, Institut Néel, Univ. Grenoble Alpes, France — [3]Institute of Nanotechnology (INT), KIT — [4]Institute for Quantum Materials and Technology (IQMT), KIT — [5]Centre Européen de Sciences Quantiques (CESQ) , Strasbourg Cedex, France

Single-molecular magnets (SMMs) have emerged as an excellent link between the two disciplines of spintronics and molecular electronics. Their ultimate small size, excellent single spin characteristics, and long coherence times at low temperatures make them promising candidates for fundamental quantum operations. In this project we investigate spin-transistors comprising a SMM trapped in a nanometer sized gap coupled to a back gate thereby forming a quantum dot. The gap is achieved by electromigration of a gold constriction. Low-noise electrical transport measurements enable the read out of the four nuclear spin states of a single terbium ion in a $TbPc_2$ double decker. First quantum algorithms, most importantly the Grover's algorithm, have been implemented on this system. Recent measurements of more complex multi-state systems such as the Tb_2Pc_3 triple decker showed that the interactions between the two terbium nuclear spins can be detected. Here we pursue to use the increased Hilbert space dimension of coupled molecular spins for more complex quantum algorithms.

TT 21.23 Wed 15:00 P1

Synthesis, structure and property investigations of low-dimensional magnetism in double perovskite variants — •Anastasiia Smerechuk, Sabine Wurmehl, Bernd Büchner, and Ryan Morrow — Leibniz Institute for Solid-State and Materials Research, IFW-Dresden, 01069 Dresden, Germany

For many years perovskites in various modifications have been occupying a significant place in solid-state physics. The main feature of these materials is a large number of possible permutations of the structure. Although perovskites are mostly three-dimensional materials, low-dimensional magnetism can also be achieved in the special case. Current research is focused on two different approaches for that purpose. Experiments with the substitution of various compounds in double perovskites with Cu^{2+} were conducted at ambient and high pressure to acquire the magnetic interactions on a square lattice. Also, our research was concentrated on defect double perovskites, where vacancies have been ordered along with the ordering of cations. Then the hexagonal phases of perovskite can be transformed into triangular frustrated two-dimensional magnets. New inorganic transition metal oxides were synthesized. The crystallographic and magnetometry data will be discussed in detail in the poster.

TT 21.24 Wed 15:00 P1

Electronic properties of strongly correlated ruthenates — •Neda Riahisamani and Eva Pavarini — Institute for Advanced Simulation, Forschungszentrum Jülich, D-52425, Germany

We study the electronic properties of strongly correlated ruthenates by using the LDA+DMFT method. We construct materials-specific models for the t_{2g} bands via maximally localized Wannier functions. We solve the DMFT quantum impurity problem by adopting as solver the weak coupling continuous-time Quantum Monte Carlo approach, in the implementation of Refs. [1, 2, 3]. General trends will be discussed.

[1] E. Gorelov, M.Karolak, T. O. Wehling, F. Lechermann, A. I. Lichtenstein, E. Pavarini, Phys. Rev. Lett. **104**, 226401 (2010)
[2] G. Zhang, E. Gorelov, E. Sarvestani, E. Pavarini, Phys. Rev. Lett. **116**, 106402 (2016)
[3] E. Sarvestani, G. Zhang, E. Gorelov, E. Pavarini, Phys. Rev. B **97**, 085141 (2018)

TT 21.25 Wed 15:00 P1

Magnetic quantum oscillations in the molecular conductor κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Cl near and away from the Mott transition — •Shamil Erkenov[1,2], Sebastian Oberbauer[1,2], Vladimir Zverev[3], Werner Biberacher[1], Natalia Kushch[1], and Mark Kartsovnik[1] — [1]Walther-Meißner-Institut, Garching, Germany — [2]Technische Universität München, Garching, Germany — [3]Chernoglovka, Russia

Magnetic quantum oscillations have been extensively used for exploring correlated-electron materials near various correlation-driven instabilities of the normal metallic state. Applying this technique to the quasi-two-dimensional bandwidth-controlled Mott insulator κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Cl, we have recently disclosed several anomalies in the behavior of the effective mass and scattering rate, apparently inconsistent with theoretical predictions. For clarifying the role of the proximity to the Mott transition in these anomalies it is instructive to track their evolution in a broader range of the phase diagram, both very close to and far away from the metal-insulator phase boundary.

To this end, we have measured quantum oscillations of magnetoresistance in the pressure interval 20 to 1000 MPa, which drives the system from the very edge of stability of the metallic phase to a "good metal" region of the phase diagram by means of the conducting bandwidth variation. We have also studied the possibility of changing the balance between the charge correlations and magnetic interactions governing the insulating instability by applying a strong magnetic field.

TT 21.26 Wed 15:00 P1

Building Blocks for Cluster Mott Insulators — •Vaishnavi Jayakumar and Ciarán Hickey — Institute for Theoretical Physics, University of Cologne, Germany

The Hubbard model provides a rich playground for investigating the physics of a wide range of strongly correlated systems. An important limit in the model is the Mott insulating regime, where, at half-filling, electrons get localized on single atomic sites. In this work, we investigate extensions of the idea to cluster Mott insulators– where electrons are now localized on clusters of sites. To that end, we study the Hubbard model on a plethora of different clusters, at different integer fillings, by constructing a general Hamiltonian for each cluster. This allows us to explore different regimes of the interplay of strong correlations and hopping within these clusters, and their respective emergent effective degrees of freedom. We then go beyond the single-orbital "cluster" Hubbard model and include multiple orbitals and interactions between them. Once these building blocks have been established, it is possible to introduce inter-cluster hopping terms into the picture; depending on the nature of the resulting effective interactions, they can give rise to novel Hamiltonians, which might possibly host highly correlated and/or frustrated phases.

TT 21.27 Wed 15:00 P1

Chern insulators in twisted bilayer graphene under hydrostatic pressure — •Israel Díaz[1], José González[2], and Tobias Stauber[1] — [1]Materials Science Factory, Instituto de Ciencia de Materiales de Madrid, CSIC, E-28049, Madrid, Spain — [2]Instituto de Estructura de la Materia, CSIC, E-28006, Madrid, Spain

It is well-known that high hydrostatic pressures can be used to induce flat bands in twisted bilayer graphene, at twist angles larger than those realizing the usual magic-angle condition. We show that these twisted graphene bilayers, tuned at such larger magic angles, are prone to fall into Chern insulator phases. We characterize such states by relying on a self-consistent real-space Hartree-Fock approach that accounts for the long-range Coulomb interaction between all the carbon atoms in the moiré unit cell, and which is exact at the Hartree-Fock level as we incorporate all the moiré minibands in the calculation. In our flat-band models with twist angles between 2 and 4 degrees, we show that a gap opens up at the charge neutrality point due to the dynamical breakdown of time-reversal invariance. At 2 hole-doping, the dominant order parameter corresponds instead to valley symmetry breaking, but there is a critical coupling of the interaction above which a gap opens up due to the condensation of the Haldane mass. These Chern insulator phases seem to be absent in twisted bilayer graphene at the usual small magic angle, probably because they are hindered by the effects of in-plane relaxation, but they become manifest at the larger twist angles we study, leading to interesting phenomena like dissipationless edge states and anomalous Hall effect.

TT 21.28 Wed 15:00 P1

Calculating moments for many-electrons systems — •Elaheh Adibi and Erik Koch — Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany

We present a technique for computing the moments $\langle E^M \rangle = \mathrm{Tr}\, H^M$ of the many-electron spectrum. Taking the trace over a basis of Slater determinants $|I\rangle$ and expressing the Hamiltonian in the same orbital basis, matrix elements $\langle I|H^M|I\rangle$ can only be non-zero when the orbital indices of the creation operators are a permutation of those of the annihilation operators. Writing the permutations in cycle notation and realizing that the trace over a cycle with different orbital indices only depends on the number of descends, we can write the trace as a sum over products of Eulerian numbers times binomial factors involving the number of orbitals and electrons. For non-interacting electrons this further simplifies to a sum over Bell polynomials.

TT 21.29 Wed 15:00 P1

Multiloop fRG analysis of the attractive Hubbard model — •Aiman Al-Eryani[1], Sarah Heinzelmann[1], Anna Kauch[2], Alessandro Toschi[2], and Sabine Andergassen[1] — [1]University of Tuebingen — [2]TU Wien

We analyse the effect of multiloop corrections in the 2D Attractive Hubbard Model. In a TU-fRG scheme where the conventional multiloop self-energy flow equations are replaced with a Schwinger-Dyson flow, we demonstrate the importance of self-energy iteration in the convergence to reference Parquet results. Furthermore, we study the feedback of the s-wave pairing fluctuations on the charge density wave order.

TT 21.30 Wed 15:00 P1

Single-boson exchange fRG application to the two-dimensional Hubbard model at weak coupling — Kilian Fraboulet[1], •Sarah Heinzelmann[1], Pietro Bonetti[2], Aiman Al-Eryani[1], Demetrio Vilardi[2], Alessandro Toschi[3], and Sabine Andergassen[1] — [1]Institut für Theoretische Physik and Center for Quantum Science, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstrasse 1, D-70569 Stuttgart, Germany — [3]Institute of Solid State Physics, Vienna University of Technology, 1040 Vienna, Austria

The functional renormalization group (fRG) is one of the most modern implementation of the renormalization group and has proven successful in the description of various many-body quantum systems, in condensed matter theory and beyond (quantum chromodynamics, nuclear physics, ...). We illustrate in this work the computational advantages of the recently introduced single-boson exchange (SBE) formulation for the one-loop fRG applied to the two-dimensional Hubbard model.

We present a detailed analysis of the physical susceptibilities and their evolution with temperature and interaction strength, both at half filling and finite doping. We find that the rest functions describing the corrections beyond the SBE contributions play a negligible role in the weak coupling regime. The SBE formulation of the fRG flow hence allows for a substantial reduction of the numerical effort in the treatment of the two-particle vertex function, paving a promising route for future multiboson and multiloop extensions.

TT 21.31 Wed 15:00 P1

Linked cluster expansions via hypergraph decompositions — •Matthias Mühlhauser and Kai Phillip Schmidt — Institute for Theoretical Physics I, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

We present a hypergraph expansion which facilitates the direct treatment of quantum-spin-models with effective many-site interactions via perturbative linked cluster expansions. The main idea is to generate all relevant subclusters and sort them into equivalence classes essentially governed by hypergraph isomorphism. Concretely, a reduced König representation of the hypergraphs is used to make the equivalence relation accessible by graph isomorphism.

[1] M. Mühlhauser and K. P. Schmidt, arXiv:2202.03366 (2022)

TT 21.32 Wed 15:00 P1

Efficient and flexible approach to simulate low-dimensional quantum lattice models with large local Hilbert spaces at the example of the Holstein model — •Thomas Köhler[1], Jan Stolpp[2], and Sebastian Paeckel[3] — [1]Uppsala University, Sweden — [2]Georg-August-Universität Göttingen, Germany — [3]University of Munich, Germany

Quantum lattice models with large local Hilbert spaces emerge across various fields in quantum many-body physics. Problems such as the interplay between fermions and phonons, the BCS-BEC crossover of interacting bosons, or decoherence in quantum simulators have been extensively studied both theoretically and experimentally. In recent years, tensor network methods have become a successful tool to treat such lattice systems numerically. Nevertheless, systems with large local Hilbert spaces remain challenging. Here, we introduce a mapping that allows to construct artificial $U(1)$ symmetries for any type of lattice model. Exploiting the generated symmetries, numerical expenses that are related to the local degrees of freedom decrease significantly. Based on an intimate connection between the Schmidt values of the corresponding matrix-product-state representation and the single-site reduced density matrix, this allows for an efficient treatment of systems with large local dimensions. We demonstrate this new mapping, provide an implementation recipe, and perform example calculations for the Holstein model at half filling. We studied systems with a very large number of lattice sites up to $L = 501$ while accounting for $N_{\mathrm{ph}} = 63$ phonons per site with high precision in the CDW phase.

TT 21.33 Wed 15:00 P1

Electronic correlations in inhomogeneous model systems: Numerical simulation of spectra and transmission — •Andreas Weh[1], Wilhelm H. Appelt[1], Andreas Östlin[2], Liviu Chioncel[2], and Ulrich Eckern[1] — [1]Institute of Physics, University of Augsburg, 86135 Augsburg — [2]EKM & ACIT, Institute of Physics, University of Augsburg, 86135 Augsburg

We investigate the effects of electronic correlations on the spectral and transport properties of inhomogeneous model systems. The models are based on the single-band Hubbard Hamiltonian, and electronic correlations are treated within dynamical mean-field theory (DMFT). In particular, continuous-time quantum Monte Carlo (CT-QMC) as well as the more recent tensor network methods (DMRG+TDVP) are employed as impurity solvers to study the spectral function of half-metallic ferromagents; a Bethe lattice as well as layered square-lattice structures are considered [1]. The transport properties through a barrier made of such a single interacting half-metallic layer is studied [2] employing the Meir–Wingreen formalism. In particular, we demonstrate that even for a single half-metallic layer, highly polarized transmissions are achievable.

[1] A. Weh, J. Otsuki, H. Schnait, H. G. Evertz, U. Eckern, A. I. Lichtenstein, L. Chioncel, Phys. Rev. Res. 2, 043263 (2020)
[2] A. Weh, W. H. Appelt, A. Östlin, L. Chioncel, U. Eckern, Phys. Status Solidi B 259, 2100157 (2021)

TT 21.34 Wed 15:00 P1

Fifth harmonic generated currents in conventional s-wave superconductor — •Pascal Derendorf and Ilya Eremin — Institut für Theoretische Physik III, Ruhr-Universität Bochum, Bochum, Germany

Recent advances in the field of THz spectroscopy allow for controlled experiments to measure the Higgs modes signature in the Fifth Harmonic Generation (FHG), which was first measured by Z. X. Wang et al [1]. Here, we analyze a periodic multicycle pulse setup, where the driving electromagnetic field solely points into the direction of a lattice vector. We investigate the role of the Higgs mode in the clean-limit FHG of a s-wave superconductor and compare it to other contributing mechanisms, such as charge density fluctuations (CDF) and the phase mode. Further, we show that the signal in the FHG is dominated by the CDF, similar to the third harmonic generated currents. We predict a double peak signature in the frequency resolved intensity amplitude of the FHG for all three mechanisms with one peak being located at $2\Omega = 2\Delta$ and the other one at $2\Omega = \Delta$. The resonant enhancement at $2\Omega = \Delta$ is indicative of the next higher order coupling to the Higgs mode implying that it carries 4Ω. The other resonance at $2\Omega = 2\Delta$ is reminiscent of the Third Harmonic Generation and could therefore describe e.g. the Higgs mode interacting with 3 single photons.

[1] Z. X. Wang et al., arXiv: 2107.07488

TT 21.35 Wed 15:00 P1

Transfer-matrix summation of path integrals for transport through nanostructures — •Alexander Hahn, Simon Mundinar, Jürgen König, and Alfred Hucht — Theoretische Physik, Universität Duisburg-Essen and CENIDE, 47048 Duisburg, Germany

We develop a transfer-matrix style approach based on the numerical iterative summation of path integrals (ISPI) scheme [1,2] to solve non-equilibrium quantum transport. The usage of a transfer-matrix approach combined with further simplifications allows for the development of a method able to work in the stationary limit (TraSPI). Additionally, using the numerical properties of the transfer-matrix element calculation and Gray code, one can use the Woodbury formula to move inside the configuration space. Afterwards, the method is applied to a single-electron transistor with a single-level quantum dot as a central island.

[1] S. Mundinar *et al.*, Phys. Rev. B **99**, 195457 (2019)
[2] S. Mundinar *et al.*, Phys. Rev. B **102**, 045404 (2020)

TT 21.36 Wed 15:00 P1

Driven magnets: Domain wall motion in ferrimagnets in an oscillating magnetic field — •Dennis Hardt and Achim Rosch — Institute for Theoretical Physics, University of Cologne, Germany

Transition regions between two magnetic domains are described by domain walls (DWs).

In this work, we numerically study a 1D ferrimagnet with anisotropy term given by a symmetric double-well potential in magnetization in z-direction. This establishes a Goldstone mode as rotation in the x-y-plane which can be activated by driving the system with an oscillating magnetic field in z-direction.

At $T = 0$ (noise-free case) this leads to a spontaneous symmetry breaking visible in the collective movement of all DWs in one direction (left or right). We also found an analytical description for this limit.

At finite temperature, DW-pairs can also be created meaning that there is a competition between the annihilation (2 DWs meet due to diffusion and driving) and the creation (due to noise).

The noise-created domain walls are driven randomly in left or right direction. This leads to a suppression of the total number of DWs compared to the non-driven thermal case.

TT 21.37 Wed 15:00 P1

Rate functions and quantum adiabatic theorem in many-body systems — •Vibhu Mishra — Institute for Theoretical Physics, Georg-August-Universität Goettingen, Friedrich-Hund-Platz 1, 37077 Goettingen, Germany

We investigate the quantum adiabatic theorem in many body systems for XXZ and ANNNI spin chains. In order to have a well-defined quantitative measure of adiabacity in the thermodynamic limit we calculate a rate function defined via the overlap between the ground state of the final Hamiltonian and the time evolved initial state. The parameters in the Hamiltonian are varied with a linear ramp and we investigate how the rate function behaves with decreasing ramping speed (adiabatic limit). Our main tool is exact diagonalization, which is complemented by bosonization in the XY phase of the XXZ spin chain.

TT 21.38 Wed 15:00 P1

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, 85748 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 subject to intense experimental and theoretical studies [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.*, Nat. Commun. **10**, 4001 (2019)

TT 22: Unconventional Superconductors

Time: Wednesday 15:00–19:15 Location: H10

Invited Talk TT 22.1 Wed 15:00 H10

Evidence for orbital loop current magnetism in Sr_2RuO_4 — R. Fittipaldi[1], R. Hartmann[2], M.T. Mercaldo[1], S. Komori[3], A. Bjørlig[4], W. Kyung[5], Y. Yasui[6], T. Miyoshi[6], L.A.B. Olde Olthof[3], C.M. Palomares Garcia[3], V. Granata[1], I. Keren[7], W. Higemoto[8], A. Suter[7], T. Prokscha[7], A. Romano[1], C. Noce[1], C. Kim[5], Y. Maeno[6], E. Scheer[2], B. Kalisky[4], J.W.A. Robinson[3], M. Cuoco[1], Z. Salman[7], A. Vecchione[1], and •A. Di Bernardo[2] — [1]CNR-SPIN, University of Salerno, Italy — [2]University of Konstanz, Germany — [3]University of Cambridge, UK — [4]Bar-Ilan University, Israel — [5]Seoul National University, South Korea — [6]Kyoto University, Japan — [7]Paul Scherrer Institute, Switzerland — [8]Japan Atomic Energy Agency

A deeper understanding of the normal-state properties of Sr_2RuO_4 is crucial also to determine its superconducting state symmetry. Using low-energy muon spin rotation spectroscopy, we have found evidence for a new form of magnetism on the surface of Sr_2RuO_4 in its normal state. We detect weak static dipolar fields with a relatively high onset temperature above 50 K. The magnetism observed is not conventional, and we demonstrate that it arises due to orbital loop currents at the reconstructed Sr_2RuO_4 surface. Our results [1] set a reference for the observation of orbital loop current magnetism in other materials and shed light onto a new mechanism that can affect the superconducting state of Sr_2RuO_4.

[1] R. Fittipaldi et al., Nat. Commun. 12, 5792 (2021)

TT 22.2 Wed 15:30 H10

Optimization of Sr_2RuO_4 thin films and devices based on single-crystals flakes — •Priyana Puliyappara Babu[1], Roman Hartmann[1], Sohaila Zaghloul Noby[1], Elke Scheer[1], Angelo Di Bernardo[1], Rosalba Fittipaldi[2], and Antonio Vecchione[2] — [1]University of Konstanz, 78457 Konstanz, Germany — [2]University of Salerno, 84084 Fisciano, Italy

Since its discovery in 1994, Sr_2RuO_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. Thin films of Sr_2RuO_4 with very low density of defects, high residual resistivity ratio (> 30) and fully metallic down to low temperatures have been grown from single crystal target of $Sr_3Ru_2O_7$. The growth parameters that can be further optimized to get fully superconducting thin films have also been identified. In parallel, we are also fabricating superconducting devices based on Sr_2RuO_4 flakes produced by mechanical exfoliation of single crystals. Different fabrication routes involving lithography patterning followed by Inductively Coupled Plasma (ICP) etching and patterning with a helium ion microscope have been successfully employed to fabricate superconducting devices from Sr_2RuO_4 single-crystal flakes.

TT 22.3 Wed 15:45 H10

Angular dependence of superfluid density in Sr_2RuO_4 — •Javier Landaeta[1], Konstantin Semeniuk[1], Joost Aretz[1], Ismardo Bonalde[2], and Elena Hassinger[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Centro de Física, Instituto Venezolano de Investigaciones Científicas, Caracas 1020-A, Venezuela

Although being extensively studied for more than 25 years, the nature of the superconducting order parameter (SOP) of Sr_2RuO_4 is still debated. In recent years, experimental evidence revealed the possibility of two component SOPs. These results constrain the SOP to only a few allowed symmetries. To get insight on the nodal structure of the SOP, we carried out a comprehensive study of the temperature dependence of the superfluid density n_s at various angles. By measuring the superconducting lower critical field $H_{c1}(T)$ in a spherical sample with ac-susceptibility, we obtained the temperature dependence of $n_s = H_{c1}(T)/H_{c1}(0)$ down to $0.03\,T_c$. Our results show that $n_s(T)$ is identical for all the studied angles showing a low temperature power law of T^2, which rules out the possibility of horizontal line nodes in Sr_2RuO_4. These results impose strong constraints over the remaining allowed symmetries for SOPs.

TT 22.4 Wed 16:00 H10

Spin-fluctuation pairing and Hund's pairing in Sr_2RuO_4 — Mercè Roig[1], Astrid T. Rømer[1], Thomas A. Maier[2], •Andreas Kreisel[3], Peter J. Hirschfeld[4], and Brian M. Andersen[1] — [1]Niels Bohr Institute, University of Copenhagen — [2]Center for Nanophase Materials Sciences, Oak Ridge National Laboratory — [3]Institut für Theoretische Physik, Universität Leipzig — [4]Department of Physics, University of Florida

The unconventional superconductor Sr_2RuO_4 has been subject of enormous experimental investigations in the last two decades, but until now the form of its order parameter has not been explicitly determined. Given the exclusion of spin-triplet superconductivity by recent experiments, the time-reversal symmetry breaking linear combinations of *s*-, *d*- and *g*-wave one-dimensional (1D) irreducible representations are strong candidates. However, also a two-dimensional representation E_g, stabilized within the so-called Hund's coupling mean-field pairing scenario, has been proposed. In this work, we examine Hund's pairing on equal footing with spin-fluctuation pairing using a three dimensional electronic structure for Sr_2RuO_4 and a model that does not exhibit clear nesting features. For the latter, the superconducting state generated by the Hund's mechanism agrees well with that from the full fluctuation exchange vertex for large J/U ratios. On the other hand, for systems characterized by a peaked finite-momentum susceptibility, spin-fluctuation pairing generally dominates over Hund's pairing. We conclude that Hund's pairing states (and therefore also the E_g pairing) are unlikely to be realized in systems like Sr_2RuO_4.

TT 22.5 Wed 16:15 H10

Thermal conductivity of the two-phase superconductor $CeRh_2As_2$ — Seita Onishi[1], •Ulrike Stockert[1], Seunghyun Khim[1], Jacintha Banda[1], Manuel Brando[1], and Elena Hassinger[1,2] — [1]MPI for Chemical Physics of Solids, Dresden, Germany — [2]Physics Department, Technical University Munich, Germany

$CeRh_2As_2$ is an unconventional superconductor with $T_c = 0.26$ K. Two neighbouring superconducting phases are observed for a magnetic field H applied along the *c*-axis with an almost constant transition field $H^\star$ of about 4 T. In addition, antiferromagnetic order, quadrupole-density-wave order and the proximity of this material to a quantum-critical point have been reported: The coexistence of these phenomena with superconductivity is currently under discussion.

We present thermal conductivity, κ, and electrical resistivity, ρ, measured on single crystals of $CeRh_2As_2$ between 60 mK and 200 K and in magnetic fields ($H \parallel c$) up to 8 T. The extrapolation of our normal-state data to zero temperature is in line with the Wiedemann-Franz law. No clear anomaly is observed in the temperature dependence of κ at any of the reported phase transitions. Instead, $\kappa(T)$ shows a pronounced, field-dependent drop below T_c which is attributed to superconductivity. The field-dependence of the normalized thermal conductivity at 120 mK exhibits a change in slope around $H^\star$, similar to the specific heat coefficient γ. Measurements at higher fields and lower T are required to confirm that this is really due to the transition between the two superconducting phases.

TT 22.6 Wed 16:30 H10

Consequences of density-wave order in a staggered Rashba superconductor — •Anastasiia Skurativska[1,2], Manfred Sigrist[1], and Mark H Fischer[3] — [1]University of Zurich, Zurich, Switzerland — [2]Donostia International Physics Center, Donostia-San Sebastian, Spain — [3]Institute for Theoretical Physics, ETH Zurich, Zurich, Switzerland

Superconductors with local inversion-symmetry breaking can exhibit properties usually associated with non-centrosymmetric systems, such as local mixing of even and odd superconducting order parameters or unusual magnetic response. An example of a system with such local non-centrosymmetricity is a stack of layers with alternating Rashba spin-orbit coupling due to mirror symmetry breaking with respect to the individual layers. Motivated by recent experiments on the Ce-based superconductor $CeRh_2As_2$, which were interpreted as showing possible quadrupole-density-wave order, we investigate the effect of density-wave order on the physics related to local inversion-symmetry breaking. In particular, we study how the partial gapping out of the Fermi surface changes the effect of local inversion-symmetry breaking.

TT 22.7 Wed 16:45 H10

Anisotropic vortex squeezing in Rashba superconductors: a manifestation of Lifshitz invariants — Lorenz Fuchs[1], •Denis Kochan[2], Christian Baumgartner[1], Simon Reinhardt[1], Sergei Gronin[3], Geoffrey Gardner[3], Tyler Tyler Lindemann[4], Michael Manfra[3], Christoph Strunk[1], and Nicola Paradiso[1] — [1]Institut für Experimentelle und Angewandte Physik, University of Regensburg, 930 40 Regensburg, Germany — [2]Institut für Theoretische Physik, University of Regensburg, 930 40 Regensburg, Germany — [3]Microsoft Quantum Purdue, Purdue University, West Lafayette, Indiana 47907 USA — [4]Birck Nanotechnology Center, Purdue University, West Lafayette, Indiana 47907 USA

Most of 2D superconductors are of type II, i.e., they are penetrated by quantized vortices when exposed to out-of-plane magnetic fields. In a presence of a supercurrent, a Lorentz-like force acts on the vortices, leading to drift and dissipation. The current-induced vortex motion is impeded by pinning at defects. Usually, the pinning strength decreases upon any type of pair-breaking interaction perturbs a system.

In the talk we will discuss surprising experimental evidences showing an unexpected enhancement of pinning in synthetic Rashba 2D superconductors when applying an in-plane magnetic field. When rotating the in-plane component of the field with respect to the driving current, the vortex inductance turns out to be highly anisotropic. We explain this phenomenon as a direct manifestation of Lifshitz invariant that is allowed in the Ginzburg-Landau free energy by symmetry when space-inversion and time-reversal symmetries are broken.

15 min. break

Invited Talk TT 22.8 Wed 17:15 H10

Role of the film geometry in the electronic reconstruction of infinite-layer nickelates on $SrTiO_3(001)$ — •Benjamin Geisler — Fakultät für Physik, Universität Duisburg-Essen

The recent discovery of superconductivity in infinite-layer $NdNiO_2$ films on $SrTiO_3(001)$ has sparked significant interest [1]. However, details of the physical mechanism behind this observation remained so far elusive, since in contrast to the thin films [2] bulk $NdNiO_2$ shows neither superconductivity nor the antiferromagnetic interactions characteristic of high-T_c cuprates.

First-principles simulations unravel the key role of the interface: Polarity mismatch drives a surprising electronic reconstruction that results in the emergence of a correlated two-dimensional electron gas (2DEG) in the $SrTiO_3(001)$ substrate. The concomitant depletion of the self-doping Nd $5d$ states renders infinite-layer nickelates close to cuprate superconductors [3,4]. Recent work identifies an unexpected interface composition that completely quenches the 2DEG, but preserves the electronic reconstruction in the nickelate film [5]. This supports the notion of nickelate superconductivity as novel quantum phase, induced in film geometry by electronic reconstruction.

[1] D. Li *et al.*, Nature **572**, 624 (2019)
[2] H. Lu *et al.*, Science **373**, 213 (2021)
[3] B. Geisler and R. Pentcheva, PRB **102**, 020502(R) (2020)
[4] B. Geisler and R. Pentcheva, Phys. Rev. Res. **3**, 013261 (2021)
[5] B. H. Goodge, B. Geisler, K. Lee, M. Osada, B. Y. Wang, D. Li, H. Y. Hwang, R. Pentcheva, L. F. Kourkoutis, arXiv:2201.03613

TT 22.9 Wed 17:45 H10

Importance of electronic correlations in nickelates — •Paul Worm[1], Liang Si[1], Motoharu Kitatani[2], Ryotaro Arita[3,4], and Karsten Held[1] — [1]Institute of Solid State Physics, TU Wien, 1040 Vienna, Austria — [2]Department of Material Science, University of Hyogo, Ako, Hyogo 678-1297, Japan — [3]RIKEN Center for Emergent Matter Sciences (CEMS), Wako, Saitama, 351-0198, Japan — [4]Research Center for Advanced Science and Technology, University of Tokyo, Komaba, Tokyo, 153-8904, Japan

Motivated by the recent discovery of superconductivity in the pentalayer nickelate $Nd_6Ni_5O_{12}$ [1], we calculate its electronic structure and superconducting critical temperature. First we analyse the compound by means of state of the art density functional theory and dynamical mean field theory (DFT+DMFT) and find that electronic correlations remove the Nd pockets from the Fermi surface, which crucially changes the filling of the Ni $d_{x^2-y^2}$ band. An *effective* single-orbital Hamiltonian can be constructed for the five layers and we show that it's properties are stunningly similar to the infinite layer case. Subsequently we solve this *effective* model within the dynamical vertex approximation to determine the transition temperature. We further study the related bilayer nickelate and propose a suitable dopant to achieve a doping level where superconductivity is expected.

[1] Nature Materials 10.1038
[2] P. Worm et al., arXiv:2111.12697 (2021)
[3] K. Held et al., Front. Phys. 9:810394 (2021)

TT 22.10 Wed 18:00 H10

Collective Modes Contributions in Third-Harmonic Generation in Non-centrosymmetric Superconductors — •Simon Klein, Matteo Puviani, and Dirk Manske — Max Planck Institute for Solid State Research, Stuttgart, Germany

Recent interest for collective amplitude (Higgs) and phase (Leggett) excitations in single- and multi-band superconductors have led to various studies focused on third-harmonic generation (THG) experiments, both for singlet s- and d-wave gap structure. A resonance in the THG intensity appears, when matching the driving frequency to the energy of the corresponding investigated mode, leading to a phase jump at the resonance frequency. We extend these studies to superconductors without an inversion symmetry, which can be effectively described by a two-band model with an order parameter, consisting of spin singlet (even parity) and spin triplet (odd parity) components. We calculate the THG signal for the non-centrosymmetric compound CePt3Si, showing that it contains contributions from three distinguishable sources, namely the Higgs mode, the Leggett mode and quasiparticles. In the clean limit, only diamagnetic Raman-like processes contribute to the THG signal, whereas the quasiparticle contributions dominate the collective modes for all singlet-triplet ratios of the gap structure. In the dirty limit, we find a significant enhancement of the Higgs mode contributions to the THG signal, due to the inclusion of non-vanishing paramagnetic diagrams. We notice a significant change in the phase jump, which helps to differentiate between diamagnetic and paramagnetic results and thus between clean and dirty superconductors.

TT 22.11 Wed 18:15 H10

High-field superconductivity in UTe_2 — •Toni Helm[1,2], Motoi Kimata[3], Kenta Sudo[3], Julia Stirnat[1,5], Atsuhiko Miyata[1], Markus König[2], Tobias Förster[1], Jean-Pascal Hornung[1,5], Gerard Lapertot[4], Jean-Pascal Brison[4], Alexandre Pourret[4], Georg Knebel[4], Dai Aoki[3], and Jochen Wosnitza[1,5] — [1]Dresden High Magnetic Field Laboratory, HZDR, Germany — [2]MPI CPfS Dresden, Germany — [3]Tohoku University, Oarai, Ibaraki, Japan — [4]CEA, IRG-PHELIQs, Grenoble, France — [5]Technical University Dresden, Gremany

The potential spin-triplet superconductor UTe_2 with $T_c = 1.6\,K$ has attracted a lot of attention recently. The material is a highly anisotropic paramagnet that exhibits a metamagnetic transition at $H_M = 35\,T$. In addition to its field-enhanced and pressure-induced superconducting ground state, high-field superconductivity (hfSC) was observed setting in for a particular field orientation just above H_M. We investigated magnetortransport and magnetic torque in pulsed magnetic fields up to 70 T for FIB-microfabricated samples of UTe_2. Our findings confirm the existence of the hfSC above 40 T for a narrow angular range around $\approx 30°$ tilt off the b axis. The upper critical field, H_{c2}, reaches almost 75 T and exhibits a temperature dependence that strongly deviates from the low-field SC phase. Excitingly, the Hall effect experiences a drastic suppression for field orientations exactly where the hfSC emerges. The anomalous angle-dependence in high field poses a challenge to the theoretical understanding of the electronic ground state of UTe_2.

TT 22.12 Wed 18:30 H10

Two bands Ising superconductivity from Coulomb interactions in monolayer $NbSe_2$ — Sebastian Hörhold, Juliane Graf, •Magdalena Marganska, and Milena Grifoni — Institute for Theoretical Physics, University of Regensburg, Germany

The nature of superconductivity in monolayer transition metal dichalcogenides is still object of debate. It has already been argued that repulsive Coulomb interactions, combined with the disjoint Fermi surfaces around the K,K' valleys and at the Γ point, can lead to superconducting instabilities in monolayer $NbSe_2$. Here, we demonstrate the two bands nature of superconductivity in $NbSe_2$. In our approach it arises from repulsive Coulomb interactions, long range (resulting in intravalley scattering) and short range (intervalley scattering), together with Ising spin-orbit coupling. The two distinct superconducting gaps, one for the upper and one for the lower spin-orbit splitted band, both consist of a mixture of s-wave and f-wave components. Using a microscopic multiband BCS approach, we derive and self-consistently solve the gap equation, demonstrating the stability of nontrivial solutions in a realistic parameter range. The temperature dependence of the gaps and of the critical in-plane field are consistent with various sets of existing experimental data. Our results, although derived for $NbSe_2$, are however universal and apply to almost all systems with disjoint Fermi surfaces connected by two competing scattering processes.

TT 22.13 Wed 18:45 H10

Superconductivity in CrB_2 under pressure: Role of electron-phonon coupling and spin-fluctuations — •Sananda Biswas[1], Andreas Kreisel[2], Ronny Thomale[3], Roser Valentí[1], and Igor Mazin[4] — [1]Goethe Universität, Frankfurt, Germany — [2]Universität Leipzig, Leipzig, Germany — [3]Julius-Maximilians-Universität Würzburg, Würzburg, Germany — [4]George Mason University, Fairfax, VA, USA

Superconductivity has recently been discovered in CrB_2 under pressure with maximum reported T_c to be 7 K. Iso-structural to MgB_2, CrB_2 exhibits spin-density-wave (SDW) ground state at ambient pressure. In this talk, I will focus on the role of spin-fluctuations and electron-phonon coupling (EPC) in determining the T_c. We have performed ab-initio density functional perturbation theory to determine the EPC of this system and to study the spin-fluctuation, random-phase-approximation (RPA) has been employed.

TT 22.14 Wed 19:00 H10

p-wave superconductivity in Luttinger semimetals — •Julia M. Link[1] and Igor F. Herbut[2] — [1]TU Dresden, Dresden, Germany — [2]Simon Fraser University, Burnaby, Canada

We consider the three-dimensional spin-orbit-coupled Luttinger semimetal of "spin" 3/2 particles in presence of weak attractive interaction in the l=1 (p-wave) channel, and determine the low-temperature phase diagram for both particle- and hole-dopings [1]. The phase diagram depends crucially on the sign of the chemical potential, with two different states (with total angular momentum j=0 and j=3) competing on the hole-doped side, and three (one j=1 and two different j=2) states on the particle-doped side. The ground state condensates of Cooper pairs with the total angular momentum j=1,2,3 are selected by the quartic, and even sextic terms in the Ginzburg-Landau free energy. Interestingly, we find that all the p-wave ground states that appear in the phase diagram, while displaying different patterns of reduction of the rotational symmetry, preserve the time reversal symmetry. The resulting quasiparticle spectrum is either fully gapped or with point nodes, with nodal lines being absent.

[1] J. M. Link and I. F. Herbut, Phys. Rev. B 105, 134522 (2022)

TT 23: Frustrated Magnets - General

Time: Wednesday 15:00–18:30 Location: H22

TT 23.1 Wed 15:00 H22

Numerical linked cluster expansion for magnetostriction of frustrated magnets — •Alexander Schwenke and Wolfram Brenig — Institute for Theoretical Physics, Technical University Braunschweig, D-38106 Braunschweig, Germany

Thermodynamic and magnetoelastic properties of the frustrated J-K-Γ quantum spin model for proximate Kitaev magnets on the honeycomb lattice in a finite magnetic field $\vec{B}$ are studied using the numerical linked cluster expansion (NLCE) [1]. Calculations are performed on clusters of sizes up to $\sim \mathcal{O}(11)$. First, the specific heat and the magnetization are analyzed for in- as well as for out-of-plane configurations of $\vec{B}$. Second, we present results of the linear magnetostriction coefficient $\lambda(\vec{B},T)$. This displays strongly anisotropic behavior and a clear indication for a field-induced transition. Third, employing exchange parameters as proposed for the proximate quantum spin-liquid (QSL) candidate α-$RuCl_3$, we show that our results for λ are very similar to recently observed experimental data [2] on this material.

[1] M. Rigol et al., Phys. Rev. Lett. **97**, 187202 (2006)
[2] V. Kocsis et al., Phys. Rev. B **105**, 094410 (2022)

TT 23.2 Wed 15:15 H22

Dynamic structure factor of the antiferromagnetic Kitaev model in large magnetic fields — •Andreas Schellenberger, Max Hörmann, and Kai Phillip Schmidt — FAU Erlangen-Nürnberg, Erlangen, Deutschland

We investigate the dynamic structure factor of the antiferromagnetic Kitaev honeycomb model in a magnetic field by applying perturbative continuous unitary transformations about the high-field limit. One- and two-quasi-particle properties of the dressed elementary spin flip excitations of the high-field polarized phase are calculated which account for most of the spectral weight in the dynamic structure factor. We discuss the evolution of spectral features in these quasi-particle sectors in terms of one-quasi-particle dispersions, two-quasi-particle continua, the formation of anti-bound states, and quasi-particle decay. In particular, a comparably strong spectral feature above the upper edge of the upmost two-quasi-particle continuum represents three anti-bound states which form due to nearest-neighbor density-density interactions.

[1]arXiv:2203.13546 [cond-mat.str-el]

TT 23.3 Wed 15:30 H22

Fractionalized quantum criticality in spin-orbital liquids from field theory beyond the leading order — Shouryya Ray[1], Bernhard Ihrig[2], •Daniel Kruti[3], John A. Gracey[4], Michael M. Scherer[2], and Lukas Janssen[1] — [1]TU Dresden — [2]University of Cologne — [3]University of Cologne and Jülich Research Centre — [4]University of Liverpool

Two-dimensional spin-orbital magnets with strong exchange frustration have recently been predicted to realise a quantum critical point in the Gross-Neveu-SO(3) universality class. In contrast to previously known Gross-Neveu-type universality classes, this quantum critical point separates a Dirac semimetal and a long-range-ordered phase, in which the fermion spectrum is only partially gapped out. Here, we characterise the quantum critical behaviour of the Gross-Neveu-SO(3) universality class by employing three complementary field-theoretical techniques beyond their leading orders. We compute the correlation-length exponent ν, the order-parameter anomalous dimension η_ϕ, and the fermion anomalous dimension η_ψ using a three-loop 4-ϵ expansion, a second-order large-N expansion (with the fermion anomalous dimension obtained even at the third order), as well as a functional renormalisation group approach. The results from the different methods agree well with each other and provide a prime benchmark for future complementary calculations. Averaging over them, we obtain the estimates $1/\nu = 1.03(15)$, $\eta_\phi = 0.42(7)$, and $\eta_\psi = 0.180(10)$ for the physically relevant case of $N = 3$ flavours of two-component Dirac fermions in 2+1 space-time dimensions.

TT 23.4 Wed 15:45 H22

Spin excitations in the frustrated helimagnet FeP — •Aleksandr Sukhanov, Yuliia Tymoshenko, Anton Kulbakov, and Dmytro Inosov — Institut für Festkörper- und Materialphysik, Technische Universität Dresden, D-01069 Dresden

The metallic compound FeP belongs to the class of materials that feature a complex noncollinear spin order driven by the magnetic frustration. While its double-helix magnetic structure with a period $\lambda_s \approx 5c$, where c is the lattice constant, was previously well determined, the relevant spin-spin interactions that lead to that ground state remain unknown. By performing extensive inelastic neutron scattering measurements, we obtained the spin-excitation spectra in a large part of the momentum-energy space. The spectra show that the magnons are gapped with a gap energy of ~5 meV. Despite the 3D crystal structure, the magnon modes display strongly anisotropic dispersions, revealing quasi-one-dimensional character of the magnetic interactions in FeP. The physics of the material, however, is not determined by the dominating exchange, which is ferromagnetic. Instead, the weaker two-dimensional antiferromagnetic interactions between the rigid ferromagnetic spin chains drive the magnetic frustration. Using linear spin-wave theory, we were able to construct an effective Heisenberg Hamiltonian with an anisotropy term capable of reproducing the observed spectra. This enabled us to quantify the exchange interactions in FeP and determine the mechanism of its magnetic frustration.

TT 23.5 Wed 16:00 H22

NMR and magnetization studies of helical correlations within the stretched diamond lattice of $LiYbO_2$ — •S. Luther[1,2], S. Wilson[3], M. M. Bordelon[3], 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]University of California, Santa Barbara, USA — [4]MPI for Chemical Physics of Solids, Dresden, Germany

The Yb-based delafossite $LiYbO_2$ hosts a stretched diamond lattice. The resulting three-dimensional geometric frustration is in strong contrast to the recently reported 2D-type Yb-based triangular-lattice delafossites. Further, the combination of a strong spin-orbit coupling together with crystalline-electric-field effects leads to a pseudospin-1/2 ground state of the Yb^{3+} ions. A recent study of $LiYbO_2$ by means of specific heat and neutron powder diffraction established the formation of helical order with non-trivial phasing between the two interpenetrating Yb sublattices below 1.1 K [1]. In order to further explore the H-T phase diagram and magnetic correlations, we performed low-temperature magnetometry and ^{7}Li NMR of polycrystalline $LiYbO_2$. Our magnetometry and $1/T_1$ NMR data are fully consistent with the reported specific-heat results. The ^{7}Li NMR spectroscopy yields a monotonic and asymmetric spectral broadening towards low temperatures in the paramagnetic state. In the helical ordered state, a spontaneous and pronounced increase of the spectral width is observed, in agreement with the neutron-diffraction experiments.

[1] Bordelon *et al.*, Phys. Rev. B **103**, 014420 (2021)

TT 23.6 Wed 16:15 H22

Nonlinear stress-strain relation of $PdCrO_2$ — •Nina Stilkerich[1,2], Hilary Noad[1], Seunghyun Khim[1], Andrew Mackenzie[1,3], and Clifford Hicks[1,4] — [1]Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, 01062 Dresden, Germany — [3]Scottish Universities Physics Alliance (SUPA), School of Physics and Astronomy, University of St. Andrews, St. Andrews KY16 9SS, United Kingdom — [4]School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom

$PdCrO_2$ is a delafossite with an antiferromagnetic triangular lattice and a Neel temperature of 38 K. It has a double-q magnetic structure, in which the direction of spin rotation alternates from layer to layer. Under uniaxial stress, $PdCrO_2$ undergoes a transition from this double- to a single-q structure. Here, we will show stress-strain data on $PdCrO_2$, collected using a piezoelectric-driven strain cell that allows simultaneous measurement of uniaxial stress and strain. We will show that the change in lattice constant across this magnetic transition is quite large and that the transition evolves in a nontrivial way as temperature is raised.

15 min. break

TT 23.7 Wed 16:45 H22

Magneto-thermodynamics of the J_1-J_2 Heisenberg antiferromagnet on the square lattice — •Andreas Honecker[1], Johannes Richter[2,3], Jürgen Schnack[4], Alexander Wietek[3], and Mike E. Zhitomirksy[5] — [1]LPTM, CY Cergy Paris Université, France — [2]Institut für Physik, Universität Magdeburg, Germany — [3]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [4]Fakultät für Physik, Universität Bielefeld, Germany — [5]Université Grenoble Alpes, CEA, IRIG, PHELIQS, France

We investigate the finite-temperature properties of the J_1-J_2 Heisenberg antiferromagnet on the square lattice in the presence of an external magnetic field. We focus on the highly frustrated regime around $J_2 \approx J_1/2$. The *H*-*T* phase diagram is investigated with particular emphasis on the finite-temperature transition into the "up-up-up-down" state that is stabilized by thermal and quantum fluctuations and manifests itself as a plateau at one half of the saturation magnetization in the quantum case. Furthermore, we discuss the enhanced magnetocaloric effect associated to the ground-state degeneracy that arises at the saturation field for $J_2 = J_1/2$. Computations for the spin-1/2 system are carried out using finite-temperature Lanczos and quantum typicality approaches.

TT 23.8 Wed 17:00 H22

One- and two-particle dynamics of the J_1-J_2-Heisenberg bilayer — •Erik Wagner and Wolfram Brenig — TU Braunschweig, Braunschweig, Germany

The antiferromagnetic J_1-J_2 Heisenberg-model on the square lattice is one of the pillars of frustrated quantum magnetism, with Néel- and collinearly ordered ground states competing for large and small J_1/J_2, and with a quantum disordered phase of still unsettled nature in between. Probing fingerprints of such phases by approaching them out of a well controlled dimer phase is one of the rationals for studying bilayer versions of frustrated spin models. Here, and 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 of the square lattice J_1-J_2-Heisenberg bilayer up to the two-triplon excitations. Evaluating the ground state energy and the one-particle dispersion up to 7th order in $J_{1,2}$ as well as the two-particle interactions and spectrum up to 5th order, we find emerging (anti-)bound two-particle states, which can be classified by total spin and real-space symmetry, consistent with results found for the J_1-only bilayer on the square lattice [1]. We analyze the phase boundary of the dimer phase with respect to one- and two-particle excitations and find reasonable agreement with recent coupled-cluster calculations [2], while also uncovering prospects for an additional phase introduced by two-particle boundstate condensation.

[1] A. Collins, C.J. Hamer, PRB 78, 054419 (2008)
[2] R.F. Bishop et al., PRB 100, 024401 (2019)

TT 23.9 Wed 17:15 H22

Entanglement measures of a frustrated spin-1/2 Heisenberg octahedral chain within the localized-magnon approach — •Olesia Krupnitska — Institute for Theoretical Physics, Technical University Braunschweig, D-38106 Braunschweig, Germany — Institute for Condensed Matter Physics, NASU, Svientsitskii Str. 1, 79011 Lviv, Ukraine

The localized-magnon theory [1] is a powerful tool for the rigorous determination of the ground state and detailed study of the thermodynamic properties of a special class of frustrated quantum Heisenberg antiferromagnets at high magnetic fields and low temperatures. We study different measures of two-spin entanglement [2] between the nearest- and between next-nearest-neighbor spins on the square of the spin-1/2 octahedral Heisenberg chain. It was shown that the localized-magnon theory can be modified for simpler calculation of concurrence [3], which may serve as a measure of the bipartite entanglement of the octahedral chain. Furthermore, we calculate the entanglement of formation and the negativity [4] within the localized-magnon concept. We demonstrate that localized-magnon theory can be straightforwardly adapted in order to calculate the respective entanglement measures for a wide class of flat-band quantum Heisenberg antiferromagnets.

[1] J. Schulenburg et al., Phys. Rev. Lett. **88**, 167207 (2002).
[2] L. Amico et al., Rev. Mod. Phys. **80**, 517 (2008).
[3] J. Strečka, O. Krupnitska and J. Richter, EPL, **132** 30004 (2020).
[4] A. Peres, Phys. Rev. Lett. **77**, 1413 (1996).

TT 23.10 Wed 17:30 H22

Interacting magnons in the easy-axis square-lattice XXZ-model and extensions towards ring exchange — •Dag-Björn Hering[1], Matthias R. Walther[2], Kai P. Schmidt[2], and Götz S. Uhrig[1] — [1]Technische Universität Dortmund, Department of Physics, Condensed Matter Theory, Otto-Hahn-Str. 4, 44227 Dortmund — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Institut für Theoretische Physik I, Staudtstraße 7, 91058 Erlangen

The method of non-perturbative continuous similarity transformations (CST) in momentum space captures the physics of the isotropic spin 1/2 antiferromagnetic Heisenberg model on the square lattice (IHM) quantitatively [1-2]. We extend these studies to single- and two-particle properties of models related to the IHM. We start with easy-axis square-lattice XXZ-model as simplemost extension of the IHM. Here, we present and discuss the CST results for the gap [3], the roton mode [4] and the bound-states [3] between the Ising limit to isotropic point in comparison to other methods. In addition, we outline further applications of the CST to models with ring-exchange [5] relevant for cuprates and the J-Q Model as an variant of ring-exchange without frustration [6].

[1] M. Powalski et al., Phys. Rev. Lett. 115, 207202 (2015)
[2] M. Powalski et al., SciPost Phys. 4, 001 (2018)
[3] S. Dusuel et al., Phys. Rev. B 81, 064412 (2010)
[4] R. Verresen et al., Phys. Rev. B 98, 155102 (2018)
[5] K. Majumdar et al., Phys. Rev. B 85, 144420 (2012)
[6] A. W. Sandvik Phys. Rev. Lett. 98, 227202 (2007)

TT 23.11 Wed 17:45 H22

Towards analyzing phase-transitions with continuous similarity transformation: Easy-axis square-lattice XXZ and J_1-J_2 models — •Matthias R. Walther[1], Dag-Björn Hering[2], Götz S. Uhrig[2], and Kai P. Schmidt[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Institut für Theoretische Physik I, Staudtstraße 7, 91058 Erlangen — [2]Technische Universität Dortmund, Department of Physics, Condensed Matter Theory, Otto-Hahn-Str. 4, 44227 Dortmund

The method of non-perturbative continuous similarity transformations (CST) in momentum space captures the physics of the isotropic spin 1/2 antiferromagnetic Heisenberg model on the square lattice (IHM) quantitatively [1,2]. We discuss the potential of the CST to study critical behavior. To this end, the easy-axis square-lattice XXZ-model serves as a straight-forward extension of the IHM with a gapped phase away from the isotropic point. Its critical behavior is described by an established mean-field theory [3]. The CST is able to capture this criticality quantitatively. For further insights on the general capability of the CST for spin models we extend the study towards the frustrated square-lattice spin 1/2 antiferromagnetic J_1-J_2 model and analyze the breakdown of the magnetically ordered quantum phases and their gapless spin wave excitations [4,5].

[1] M. Powalski et al., Rev. Lett. 115, 207202 (2015)
[2] M. Powalski et al., SciPost Phys. 4, 001 (2018)
[3] W. Zheng et al., Phys. Rev. B 71, 184440 (2005)
[4] Götz S. Uhrig et al., Phys. Rev. B 79, 092416 (2009)
[5] R. R. P. Singh et al., Phys. Rev. Lett. 91, 017201 (2003)

TT 23.12 Wed 18:00 H22

"Stripe-yz" magnetic order in $KCeS_2$ — •Anton Kulbakov[1,2], Stanislav Avdoshenko[3], Inés Puente-Orench[4,5], Jacques Ollivier[5], Mahmoud Deeb[1], Mathias Doerr[1], Philipp Schlender[6], Thomas Doert[6], and Dmytro Inosov[1,2] — [1]IFMP, TU Dresden, Germany — [2]Würzburg-Dresden ct.qmat, TUD, Dresden, Germany — [3]IFW, Dresden, Germany — [4]INMA, Zaragoza, Spain — [5]ILL, Grenoble, France — [6]Fakultät für Chemie und Lebensmittelchemie, TU Dresden, Germany

We have solved the magnetic structure for the antiferromagnetic state below $T_N = 400$ mK, which was recently revealed in the effective spin-1/2 triangular-lattice antiferromagnet $KCeS_2$. It represents the so-called "stripe-yz" type of antiferromagnetic order with spins lying approximately in the triangular-lattice planes orthogonal to the nearest-neighbor Ce—Ce bonds, possibly with a small out-of-plane canting of the magnetic moments. The thermal expansion remains very small below 120 K, which we confirmed for the c lattice constant using capacitive dilatometry. Our experimental results also indicate that cerium oxysulphide, Ce_2O_2S, which was present in our sample as a minority phase, does not order magnetically down to 20 mK and may therefore represent a promising spin-liquid candidate deserving a separate study. For details, see [1]. Neutron time-of-flight spectroscopy of low-energy excitations in the ordered state of $KCeS_2$ reveals an unusual spin-wave band with an intensity maximum at $\mathbf{Q} = 0$, unlike in $KCeO_2$ and $KYbSe_2$.

[1] J. Phys.: Condens. Matter **33**, 425802 (2021)

TT 23.13 Wed 18:15 H22

Quantum Skyrmion lattices in Heisenberg ferromagnets — •Andreas Haller, Solofo Groenendijk, Alireza Habibi, Andreas Michels, and Thomas L. Schmidt — Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg

Skyrmions are topological magnetic textures that can arise in non-centrosymmetric ferromagnetic materials. In most systems experimentally investigated to date, skyrmions emerge as classical objects. However, the discovery of skyrmions with nanometer length scales has sparked interest in their quantum properties. In this talk, we present the results of our matrix product state simulations of the ground states of two-dimensional spin-1/2 Heisenberg lattices with Dzyaloshinskii-Moriya interactions. We discovered a broad region in the zero-temperature phase diagram which hosts quantum skyrmion lattices. The quantum skyrmion lattice phase can be detected experimentally in the magnetization profile via local magnetic polarization measurements as well as in the spin structure factor measurable via neutron scattering experiments. Finally, we show the real-space polarization profile of individual quantum skyrmions and show that it is a non-classical state featuring entanglement between quasiparticle and environment mainly localized near the boundary spins of the skyrmion.

TT 24: Quantum-Critical Phenomena

Time: Wednesday 15:00–19:00 Location: H23

TT 24.1 Wed 15:00 H23

Quantum criticality on a compressible lattice — •Saheli Sarkar, Lars Franke, Nikolas Grivas, and Markus Garst — Karlsruhe Institute of Technology, Karlsruhe, Germany

As an example of quantum criticality on a compressible lattice we study the Lorentz invariant Φ^4 theory with an N-component field Φ, where strain couples to the square of the order parameter. In three spatial dimensions this coupling as well as the self-interaction of the Φ field are both marginal on the tree-level. We compute the one-loop renormalization group equations treating the Φ field as well as the phonons on the same footing. We find that the velocities of the Φ field as well as of the phonons are renormalized yielding an effective dynamical exponent $z > 1$. The renormalization group flow is found to depend on the number of components N. Whereas we find run-away flow for $N < 4$ a new fixed-point emerges for $N >= 4$. We discuss the relation to known results for classical criticality. Our findings are directly relevant to insulating quantum critical antiferromagnets.

TT 24.2 Wed 15:15 H23

Metallic and deconfined quantum criticality in Dirac systems — •Zihong Liu[1], Matthias Vojta[2], Fakher Assaad[1], and Lukas Janssen[2] — [1]Institut für Theoretische Physik und Astrophysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany — [2]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany

Motivated by the physics of spin-orbital liquids, we study a model of interacting Dirac fermions on a bilayer honeycomb lattice at half filling, featuring an explicit global SO(3)×U(1) symmetry. Using large-scale auxiliary-field quantum Monte Carlo (QMC) simulations, we locate two zero-temperature phase transitions as function of increasing interaction strength. First, we observe a continuous transition from the weakly-interacting semimetal to a different semimetallic phase in which the SO(3) symmetry is spontaneously broken and where two out of three Dirac cones acquire a mass gap. The associated quantum critical point can be understood in terms of a Gross-Neveu-SO(3) theory. Second, we subsequently observe a transition towards an insulating phase in which the SO(3) symmetry is restored and the U(1) symmetry is spontaneously broken. While strongly first order at the mean-field level, the QMC data is consistent with a direct and continuous transition. It is thus a candidate for a new type of deconfined quantum critical point that features gapless fermionic degrees of freedom.

TT 24.3 Wed 15:30 H23

Deconfined multi-critical point — •Zhenjiu Wang[1] and Adam Nahum[2] — [1]Max-Planck Institute for the Physics of Complex Systems, D-01187, Dresden, Germany — [2]Laboratoire de Physique, Ecole Normale Superieure, CNRS, Universit*e PSL, * Sorbonne Universite, Universite de Paris, 75005 Paris, France

We numerically investigate a deconfined quantum critical point (DQCP) that happens between Neel and valence bond solid phase in a 3-dimensional loop model. Amazingly, this DQCP is an Liftshitz tricritical point due to an explicit lattice symmetry breaking term. This perturbation breaks lattice translational symmetry as well as a mirror-reflection symmetry whereas production of these two operations leave system invariant, hence only an additional vector potential term is coupled to the non-linear sigma model in IR theory. A helical valence bond solid state with spatially modulated valence bond order parameter separates VBS and Neel state due to this explicit vector potential, and a continuous phase transition between Neel and HVB state is simply described by the criticality of DQCP with an emergent Lorenz invariance in IR limit.

TT 24.4 Wed 15:45 H23

Specific heat and magnetocaloric effect at transverse-field quantum criticality in $LiHoF_4$ — •Andreas Wendl[1], Heike Eisenlohr[2], Jan Spallek[1], Christopher Duvinage[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 $LiHoF_4$ under a transverse field [1-3]. We report an experimental and theoretical study of the specific heat and magneto-caloric effect of $LiHoF_4$ as a function magnetic field down to mK temperatures using a bespoke experimental set-up permitting studies under arbitrary magnetic field orientations. We derive the low temperature entropy landscape and discuss our findings in terms of a theoretical model taking quantitatively 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. Ronnow et al., Science **308**, 389 (2005)
[3] P. B. Chakraborty et al., Phys. Rev. B **70**, 144411 (2004).

TT 24.5 Wed 16:00 H23

Muon spin rotation and relaxation study on $Nb_{1-y}Fe_{2+y}$ — •Jannis Willwater[1], Daniela Eppers[1,2], Thomas Kimmel[1], Elaheh Sadrollahi[1,3], Jochen Litterst[1], Malte Grosche[4], Christopher Baines[5], and Stefan Süllow[1] — [1]IPKM, TU Braunschweig, Germany — [2]PTB, Braunschweig, Germany — [3]IFMP, TU Dresden, Germany — [4]Cavendish Laboratory, University of Cambridge, United Kingdom — [5]PSI, Villigen, Switzerland

The study of metallic materials with a ferromagnetic quantum critical transition revealed a plethora of novel and exotic behavior. In $Nb_{1-y}Fe_{2+y}$, a well-known example, the magnetic ground state reacts extremely sensitively to the chemical composition. Previous experiments show that by varying y, two ferromagnetic ultralow-moment and a SDW phase can be reached in the phase diagram. In particular, the magnetism disappears in a narrow range which is associated with the occurrence of a quantum critical point.

Here, we present a comprehensive study of the magnetic behaviour of $Nb_{1-y}Fe_{2+y}$ by means of muon spin rotation and relaxation. After establishing the muon stopping site, we studied and validated the magnetic phase diagram on different single and polycrystals. The focus of our study was the first investigation of a quantum critical sample, which shows no signs of long-range order, using a microscopic measurement technique. We demonstrate that magnetism at the lowest temperatures is dominated by magnetic fluctuations and that $Nb_{1-y}Fe_{2+y}$ emerges to be uniquely suited to study quantum criticality close to weak itinerant ferromagnetic order.

TT 24.6 Wed 16:15 H23

Quantum criticality of the long-transverse-field Ising model extracted by Quantum Monte Carlo simulations — •Jan Alexander Koziol, Anja Langheld, Sebastian C. Kapfer, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

The quantum criticality of the ferromagnetic transverse-field Ising model with algebraically decaying interactions is investigated by means of stochastic series expansion quantum Monte Carlo, on both the one-dimensional linear chain and the two-dimensional square lattice. Utilizing finite-size scaling (FSS), we extract the full set of critical exponents as a function of the decay exponents of the long-range interactions. We resolve the three different regimes predicted by field theory, ranging from the nearest-neighbor Ising to the long-range Gaussian universality classes with an intermediate regime giving rise to a continuum of critical exponents. Focusing on the non-trivial intermediate regime, we verify our study by the well-known limiting regimes. In the long-range Gaussian regime, we treat the effect of dangerous irrelevant variables on the homogeneity laws by means of a modern FSS formalism.

TT 24.7 Wed 16:30 H23

Quantum criticality of the long-range antiferromagnetic Heisenberg ladder — •Patrick Adelhardt and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg

The Mermin-Wagner theorem excludes the breaking of a continuous symmetry in one-dimensional spin systems at zero temperature for sufficiently short-ranged interactions. Introducing algebraically decaying long-range couplings on the antiferromagnetic Heisenberg two-leg ladder, we show that a direct second-order quantum phase transition between the topologically ordered rung-singlet phase in the short-range limit and a conventionally Néel-ordered antiferromagnet can be realized in a one-dimensional system. We study the quantum-critical breakdown in the rung-singlet phase using the method of perturbative continuous unitary transformations (pCUT) on white graphs in combination with classical Monte Carlo simulations for the graph embedding in the thermodynamic limit supplemented with linear spin-wave calculations to extract the critical point. Exploiting (hyper-)scaling relations, the pCUT method is used to determine the entire set of canonical critical exponents as a function of the decay exponent. We find that the critical behavior can be divided into a long-range mean-field regime and a regime of continuously-varying exponents similar to the long-range transverse-field Ising model despite the presence of distinct orders on different sides of the critical point and the absence of criticality in the short-range limit.

TT 24.8 Wed 16:45 H23

Electronuclear quantum criticality — Jacintha Banda[1], Daniel Hafner[1], Javier F. Landaeta[1], Elena Hassinger[1,2], Keisuke Mitsumoto[3], Mauro Giovannini[4], Julian Sereni[5], Christoph Geibel[1], and •Manuel Brando[1] — [1]Max Planck Institute for Chemical Physics of Solids, D-01187 Dresden, Germany — [2]Technical University Munich, Physics department, 85748 Garching, Germany — [3]Liberal Arts and Sciences, Toyama Prefectural University, Imizu, Toyama 939-0398, Japan — [4]Department of Chemistry and Industrial Chemistry (DCCI), University of Genova, 16100 Genova, Italy — [5]Department of Physics, CAB-CNEA, CONICET, 8400 San Carlos de Bariloche, Argentina

We present here a rare example of electronuclear quantum criticality in a metal. The compound $YCu_{4.6}Au_{0.4}$ is located at an unconventional quantum critical point (QCP). The relevant Kondo and RKKY exchange interactions are very weak, of the order of 1 K with a strong competition between antiferromagnetic and ferromagnetic correlations, possibly due to geometrical frustration within the fcc Yb sublattice. This causes strong spin fluctuations which prevent the system to order magnetically. Because of the very low Kondo temperature the Yb^{3+} $4f$-electrons couple weakly with the conduction electrons allowing the coupling to the nuclear moments of the ^{171}Yb and ^{173}Yb isotopes to become important. Thus, the quantum critical fluctuations observed at the QCP derive not from purely electronic states but from entangled 'electronuclear' states. This is evidenced in the anomalous temperature and field dependence of the specific heat at very low temperatures.

15 min. break

TT 24.9 Wed 17:15 H23

Bosonization duality in 2+1 dimensions and critical current correlation functions in Chern-Simons U(1)*U(1) Abelian Higgs model — •Vira Shyta[1], Flavio Nogueira[1], and Jeroen van den Brink[1,2] — [1]Institute for Theoretical Solid State Physics, IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany — [2]Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01069 Dresden, Germany

While the phase structure of the U(1)*U(1)-symmetric Higgs theory is still under debate, we have shown that a version of this theory with an additional Chern-Simons term undergoes a second-order phase transition. We established that such a theory is a bosonized dual of a topological field theory of massless fermions featuring two gauge fields. Here we elaborate on several aspects of this duality, focusing on the critical current correlators and on the nature of the critical point as reflected by the bosonization duality. The current correlators associated to the U(1)*U(1) symmetry and the topological current are shown to coincide up to a universal prefactor, which we find to be the same for both U(1) and U(1)*U(1) topological Higgs theories. The established duality offers in addition another way to substantiate the claim about the existence of a critical point in the bosonic Chern-Simons U(1)*U(1) Higgs model: a Schwinger-Dyson analysis of the fermionic dual model shows that no dynamical mass generation occurs. The same cannot be said for the theory without the Chern-Simons term in the action.

TT 24.10 Wed 17:30 H23

Fixed-point structure and critical behavior of generalized Gross-Neveu models in 2+1 dimensions — •Konstantinos Ladovrechis, Shouryya Ray, Tobias Meng, and Lukas Janssen — Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

The universal behavior of matter near points of continuous phase transitions is an intriguing phenomenon in condensed matter and statistical physics. At quantum critical points, the presence of gapless fermion degrees of freedom leads to new quantum universality classes without any classical analogues. Here, we discuss zero-temperature phase transitions between two-dimensional Dirac semimetals and long-range-ordered phases, in which spin and/or charge symmetries are spontaneously broken. These transitions are described by generalized Gross-Neveu models in 2+1 dimensions. We identify and classify fixed points of the renormalization group in the theory space spanned by a basis of short-range interactions compatible with the given symmetries, and we compute the corresponding quantum critical behaviors. Implications for the physics of interacting Dirac systems will be discussed as well.

TT 24.11 Wed 17:45 H23

Torus spectroscopy of the chiral Heisenberg quantum phase transition — •Thomas C. Lang[1], Davide Breoni[1,2], Seth Whitsitt[3], Michael Schuler[1], Stefan Wessel[4], and Andreas M. Läuchli[1,5] — [1]Institute for Theoretical Physics, University of Innsbruck, Austria — [2]Institute for Theoretical Physics II: Soft Matter, Heinrich Heine-Universität Düsseldorf, Germany — [3]Joint Quantum Institute, NIST and the University of Maryland, College Park, Maryland, USA — [4]Institut für Theoretische Festkörperphysik, JARA-FIT and JARA-HPC, RWTH Aachen University, 52056 Aachen, Germany — [5]Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland

We establish the universal torus low-energy spectra at the strongly coupled chiral Heisenberg fixed point in $D = (2+1)$ dimensions by means of quantum Monte Carlo simulations and exact diagonalization. The fixed point and the associated Gross-Neuveu-Yukawa field theory are directly relevant for the long-wavelength physics of certain interacting Dirac systems, such as repulsive spinfull fermions on the honeycomb lattice, or π-flux square lattice and are compared against results from SLAC fermions. The torus energy spectrum has been shown previously to serve as a characteristic fingerprint of relativistic fixed points and is a powerful tool to discriminate quantum critical behavior in numerical simulations. We are able to address the subtle crossover physics of the low-energy spectrum flowing from the Dirac fixed point to the chiral Heisenberg fixed point, and compare against earlier attempts to extract the Fermi velocity renormalization.

TT 24.12 Wed 18:00 H23

Finite size spectrum of the staggered six-vertex model with $U_q(\mathfrak{sl}(2))$-invariant boundary conditions — •Sascha Gehrmann[1] and Holger Frahm[2] — [1]Institute of Theoretical Physics, Leibniz University Hannover, Germany — [2]Institute of Theoretical Physics, Leibniz University Hannover, Germany

The finite-size spectrum of the critical $\mathbb{Z}_2$-staggered spin-1/2 XXZ model with quantum group invariant boundary conditions is presented. The conformal weights, which are found to have a continuous component, can be described in terms of the non-compact $SU(2,\mathbb{R})/U(1)$ Euclidean black hole conformal field theory (CFT) for a range of the staggering parameter. Besides the continuous part of the spectrum of this CFT, we find also levels from the discrete part emerging as the anisotropy is lowered. The finite size amplitudes of both the continuous and the discrete levels can be parameterized by the corresponding eigenvalues of a quasi-momentum operator which commutes with the Hamiltonian and the transfer matrix of the model.

TT 24.13 Wed 18:15 H23

Fixed-point annihilation and duality in the SU(2)-symmetric spin-boson model — •Manuel Weber[1] and Matthias Vojta[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

The annihilation of two intermediate-coupling renormalization-group (RG) fixed points is of interest in diverse fields from statistical mechanics to high-energy physics and has so far been studied using perturbative techniques. Here we present high-accuracy quantum Monte Carlo results for the SU(2)-symmetric $S = 1/2$ spin-boson (or Bose-Kondo) model. We study the model with a power-law bath spectrum $\propto \omega^s$ where, in addition to a critical phase predicted by perturbative RG, a stable strong-coupling phase is present. Using a detailed scaling analysis, we provide direct numerical evidence for the collision and annihilation of two RG fixed points at $s^* = 0.6540(2)$, causing the critical phase to disappear for $s < s^*$. Moreover, we uncover a surprising duality between the two fixed points, corresponding to a reflection symmetry of the RG beta function, which we utilize to make analytical predictions at strong coupling which are in excellent agreement with numerics. We comment on the consequences for impurity moments in critical magnets.

TT 24.14 Wed 18:30 H23

Applying continuous unitary transformations to open quantum systems — •Lea Lenke, Matthias Mühlhauser, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We generalize the method of continuous unitary transformations (CUTs) to certain types of open systems. In some cases – such as gain-loss Hamiltonians – there exists an effective description in terms of non-Hermitian Hamiltonians. For the latter we successfully apply a perturbative CUT (pCUT) to two non-Hermitian PT-symmetric quantum spin models in order to determine their low-energy physics [1]. In a next step, we aim at generalizing this method further to dissipative frustrated systems described by a Lindblad master equation.

[1] L. Lenke, M. Mühlhauser, K. P. Schmidt, Phys. Rev. B 104, 195137 (2021)

TT 24.15 Wed 18:45 H23

Finite-size scaling at quantum phase transitions above the upper critical dimension — •Anja Langheld, Jan Alexander Koziol, Patrick Adelhardt, Sebastian C. Kapfer, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

The hyperscaling relation and standard finite-size scaling (FSS) are known to break down above the upper critical dimension due to dangerous irrelevant variables. The upper critical dimension becomes experimentally accessible, for instance, in systems with long-range interactions such as the long-range transverse-field Ising model, which can be realized in systems of trapped ions.

We present a coherent formalism for FSS at quantum phase transitions above the upper critical dimension following the recently introduced Q-FSS formalism for thermal phase transitions. Contrary to long-standing belief, the correlation sector is affected by dangerous irrelevant variables. The presented formalism recovers a generalized hyperscaling relation and FSS form.

Using this new FSS formalism, we determine the full set of critical exponents for the long-range transverse-field Ising chain in all criticality regimes ranging from the nearest-neighbor to the long-range mean field regime. For the same model, we also explicitly confirm the effect of dangerous irrelevant variables on the characteristic length scale.

TT 25: Topological Semimetals

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

Invited Talk TT 25.1 Thu 9:30 H3

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

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

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

TT 25.2 Thu 10:00 H3

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

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

TT 25.3 Thu 10:15 H3

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

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

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

TT 25.4 Thu 10:30 H3

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

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

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

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

TT 25.5 Thu 10:45 H3

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

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

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

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

TT 25.6 Thu 11:00 H3

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

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

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

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

15 min. break

TT 25.7 Thu 11:30 H3

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

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

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

TT 25.8 Thu 11:45 H3

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

Trigonal $PtBi_2$ represents an exceptional playground for the exploration of topological materials. In fact, it is a Weyl semimetal with broken inversion symmetry and strong spin-orbit coupling, showing also superconductivity at low temperatures. The Nernst effect has been proven to be a powerful technique to investigate the fermiology of unconventional materials. Moreover, in systems characterized by non-trivial topology, the Nernst coefficient often assumes distinctive features, as observed in various Weyl semimetals. In this work, we deeply investigate the evolution of the Nernst coeffcient in a sigle crystal of trigonal-$PtBi_2$ as a function of different parameters: temperature (T), magnetic field (B) and angle (ŏ3b8) between the magnetic field direction and the c-axis of the sample. In particular, we found an anomalous phenomenology, which could be ascribed to peculiar properties of the Fermi surface.

TT 25.9 Thu 12:00 H3

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

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

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

TT 25.10 Thu 12:15 H3

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

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

Work supported by DFG EXC-2123-390837967 Quantum-Frontiers, DFG Le967/16-1, DFG-RTG 1952/1, and the Quantum- and Nano-Metrology (QUANOMET) initiative of Lower Saxony within project NL-4.

TT 25.11 Thu 12:30 H3

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

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

TT 25.12 Thu 12:45 H3

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

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

TT 25.13 Thu 13:00 H3

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

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

TT 26: Superconductivity: Tunnelling and Josephson Junctions

Time: Thursday 9:30–13:00 Location: H10

TT 26.1 Thu 9:30 H10

Microwave spectroscopy of a long Josephson junction strongly coupled to a resonator — •Micha Wildermuth[1], Mikhail Fistul[2], Jan Nicolas Voss[1], Andre Schneider[1], Hannes Rotzinger[1,3], and Alexey V. Ustinov[1,3] — [1]Institute of Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Theoretische Physik III, Ruhr-Universität Bochum, 44801 Bochum Germany — [3]Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Long Josephson junctions are interesting physical systems due to their strongly nonlinear spatial and temporal dynamics. In the past, most of experiments were performed by coupling long junctions galvanically to measurement lines and recording their DC current-voltage characteristics. Here we explore an alternative approach, where the long junction is attached to a passive microwave resonator and the whole coupled system is measured with an RF technique. This configuration opens up new opportunities of low-dissipative tests and applications, in particular, for Josephson vortex qubits. We present fabrication results, microwave spectroscopy data and numerical simulations of this high-impedance hybrid system.

TT 26.2 Thu 9:45 H10

Quantum interference in a 1d array of three-terminal Josephson junctions — •Johanna Berger[1], Christian Baumgartner[1], Lorenz Fuchs[1], Sergei Gronin[2], Geoff Gardner[2], Michael Manfra[2], Nicola Paradiso[1], and Christoph Strunk[1] — [1]Experimental and Applied Physics, University of Regensburg (Germany) — [2]Purdue University, West Lafayette, Indiana (USA)

We present DC transport measurements of an 1d array of three-terminal Josephson junctions based upon an epitaxial Al-InAs heterostructure. Two terminals are connected via a superconducting loop. Under the influence of perpendicular magnetic fields the critical current displays a complex diffraction pattern resembling the superposition of a Fraunhofer pattern-like envelope and SQUID oscillations. In the presence of an additional in-plane magnetic field this pattern develops two asymmetries: The main lobe shows clear supercurrent diode behavior [1], which results in different critical currents depending on the applied current direction. With increasing in-plane magnetic field the diffraction pattern acquires an overall skewness with respect to the perpendicular magnetic field, leading to differently pronounced side lobes. Unlike the diode effect this skewness is not suppressed at higher magnetic fields.

[1] C. Baumgartner *et. al.*, Nat. Nanotechnol. **17**, 39 (2022)

TT 26.3 Thu 10:00 H10

Highly-packed Nb-C Josephson junction arrays prepared by focused-ion-beam nanoprinting — •Fabrizio Porrati[1], Felix Jungwirth[1], Sven Barth[1], Gian Carlo Gazzadi[2], Stefano Frabboni[2], Oleksandr V. Dobrovolskiy[3], and Michael Huth[1] — [1]Goethe-University, Institut of Physics, Frankfurt a. M. — [2]Nanoscience Institute-CNR, Modena — [3]University of Vienna, Faculty of Physics, Vienna

Focused ion beam-induced deposition (FIBID) is a direct-write technique for the fabrication of nanostructures of any shape and dimension with high lateral resolution. Here, FIBID is employed to prepare Josephson junction arrays (JJA) consisting of superconducting Nb-C dots coupled through the proximity effect via a thin granular metal layer. The fabrication of the device is straightforward and it takes place in a few seconds. The microstructure and the composition of the JJA are investigated by transmission electron microscopy (TEM) and energy dispersive x-ray spectroscopy (EDS). The superconductor-to-metal transition of the JJA is studied directly by tuning the Josephson junction resistance in 70 nm-spaced Nb-C dots. The observed magnetoresistance oscillations with a period determined by the flux quantum give evidence for the coherent charge transport by paired electrons.

TT 26.4 Thu 10:15 H10

A particle conserving approach to AC-DC driven interacting quantum dots with superconducting leads — •Julian Siegl, Jordi Picó-Cortés, and Milena Grifoni — Universität Regensburg, Regensburg, Germany

The combined action of a DC bias and a microwave drive on the transport characteristic of a superconductor-quantum dot-superconductor junction is investigated. To cope with non-equilibrium effects and interactions in the quantum dot, we develop a general formalism for the dynamics of the density operator based on a particle conserving approach to superconductivity. An exact generalized master equation for the reduced dot operator is obtained that treats the interaction inside the dot exactly and showcases the characteristic bichromatic response due to the combination of the AC Josephson effect and an AC voltage. In the weak coupling limit, analytical expressions for the stationary current and the reduced dot operator are provided. In this regime, beside quasiparticle transport, we show that superconducting correlations manifest in anomalous pair tunneling processes involving the tunneling of a Cooper pair. Photon assisted processes allow for subgap transport and rich current-voltage characteristics. For example, we find total current inversion, in which the current flows against the applied DC bias for suitable parameter regimes.

TT 26.5 Thu 10:30 H10

Model-independent determination of the gap function of nearly localized superconductors — •Dušan Kavický[1], František Herman[1,2], and Richard Hlubina[1] — [1]Department of Experimental Physics, Comenius University, Mlynská Dolina F2, 842 48 Bratislava, Slovakia — [2]Institute for Theoretical Physics, ETH Zurich, CH-8093, Switzerland

The gap function $\Delta(\omega)$ carries essential information on both, the pairing glue as well as the pair-breaking processes in a superconductor. Unfortunately, in nearly localized superconductors with a non-constant density of states in the normal state, the standard procedure for extraction of $\Delta(\omega)$ cannot be applied. Here, we introduce a model-independent method that makes it possible to extract $\Delta(\omega)$ also in this case. The feasibility of the procedure is demonstrated on the tunneling data for the disordered thin films of TiN. We find an unconventional feature of $\Delta(\omega)$ which suggests that the electrons in TiN are coupled to a very soft pair-breaking mode.

TT 26.6 Thu 10:45 H10

The DC Josephson effect for a single level weak link: a Green's function formulation within a particle conserving theory of superconductivity — •Anton Bleibaum and Milena Grifoni — Institute for Theoretical Physics, University of Regensburg, 93053 Regensburg, Germany

In traditional transport set-ups a current only flows when a bias voltage is applied. In the presence of superconducting electrodes a supercurrent can flow through a tunneling barrier even in thermodynamic equilibrium. This phenomenon is called DC-Josephson effect. Most of its features can be captured within mean field BCS-theory, according to which the supercurrent is a function of the phase difference between the two superconductors.

How can this result be reconciled with charge conservation in a physical system? In this work we compute the DC Josephson current in transport set-ups consisting of two superconducting electrodes coupled to a single level non-interacting quantum dot. The computation is based on a particle conserving theory of superconductivity. We first provide a current formula in terms of particle conserving Green's functions. In a second step the infinite hierarchy of equations for the relevant Green's function is solved. The Andreev bound states spectrum naturally follows from the poles of the retarded Green's function, and the DC-current has the form known from BCS theory.

TT 26.7 Thu 11:00 H10

Engineering the speedup of quantum tunneling in Josephson systems via dissipation — •Dominik Maile[1], Joachim Ankerhold[1], Sabine Andergassen[2], Wolfgang Belzig[3], and Gianluca Rastelli[4] — [1]Institut für komplexe Quantensysteme, Universität Ulm, Germany — [2]Institut für Theoretische Physik, Universität Tübingen, Germany — [3]Fachbereich Physik, Universität Konstanz, Germany — [4]NO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, Povo, Italy

We theoretically investigate the escape rate occurring via quantum tunneling in a system affected by tailored dissipation [1]. Specifically, we study the environmental assisted quantum tunneling of the superconducting phase in a current-biased Josephson junction. We consider Ohmic resistors inducing dissipation both in the phase and in the charge of the quantum circuit. We find that the charge dissipation leads to an enhancement of the quantum escape rate. This effect appears already in the low Ohmic regime and also occurs in the presence of phase dissipation that favors localization. Inserting realistic circuit parameters, we address the question of its experimental observability and discuss suitable parameter spaces for the observation of the enhanced rate.

[1] D. Maile, J. Ankerhold, S. Andergassen, W. Belzig, G. Rastelli, arXiv:2203.08075 (2022)

15 min. break

TT 26.8 Thu 11:30 H10

Nonreciprocity in current-biased Josephson junctions in the presence of Yu-Shiba-Rusinov bound states — •Martina Trahms[1], Bharti Mahendru[1], Idan Tamir[1], Larissa Melischek[1], Jacob F. Steiner[1], Nils Bogdanoff[1], Olof Peters[1], Gaël Reecht[1], Clemes B. Winkelmann[2], Felix von Oppen[1], and Katharina J. Franke[1] — [1]Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [2]Univ. Grenoble Alpes, Institute Néel, 38042 Grenoble, France

Magnetic impurities on superconducting surfaces are known to locally disturb Cooper pairs and form Yu-Shiba-Rusinov (YSR) states. We employ current-biased Josephson spectroscopy in a scanning tunnelling microscope to study the phase dynamics of Josephson junctions in the presence of YSR states. For that purpose Mn and Cr adatoms are evaporated on a superconducting Pb(111) surface and investigated with a superconducting Pb tip. We observe switching currents that are significantly larger than the retrapping currents, identifying the junction as underdamped. In the presence of magnetic atoms, a local reduction of switching currents is observed. Additionally, we find a nonreciprocal behavior of the retrapping currents with respect to the current-sweep direction, i.e., the absolute value of the retrapping current depends on whether the current sweep starts at positive or negative bias values. In our experiment both species of magnetic atoms lead to a nonreciprocal retrapping-current behavior, albeit with a different directionality. We suggest a correlation between the damping of the Josephson junction and the electron-hole asymmetry of the YSR states.

TT 26.9 Thu 11:45 H10

Josephson effect through 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 Technologies, German Aerospace Center (DLR), Ulm, Germany

A mK-STM functionalized with a magnetic impurity at the tip can probe a sample with a second impurity, thus realizing tunneling between Yu-Shiba-Rusinov (YSR) states [1]. We study the Josephson effect in such a system as a sensitive probe of the magnetic orientation of the impurities. Using Keldysh Green's functions, we show that the subgap bound states are spin-polarized and give rise to a spin polarized Josephson current. At low transmission, the YSR states of the impurities hybridize weakly, whereas at large transmission, the bound states are strongly phase-dependent, resembling spin split Andreev bound states [2]. The spin structure of the current becomes strongly phase-dependent. For aligned or anti-aligned magnetic impurities, we show that an unusual quantum phase transition emerges. While such a Josephson current can be used as a sensitive spin probe, we find that it is accompanied by significant feedback in the form of a Josephson spin torque acting to align/anti-align the impurities.

[1] H. Huang *et al.*, Nat. Phys. **16**, 1227 (2020)
[2] B. Bujnowski *et al.*, EPL **115**, 67001 (2016)

TT 26.10 Thu 12:00 H10

Spin-orbit coupling assisted transport phenomena in superconducting magnetic tunnel junctions — •Andreas Costa and Jaroslav Fabian — University of Regensburg, Germany

Superconducting magnetic junctions exhibit fascinating physical phenomena, making them essential building blocks for modern technologies like quantum computing. Particularly attractive are multicomponent junctions in which the broken space-inversion symmetry additionally rises strong spin-orbit coupling (SOC). Pairing the interplay of these two most important spin interactions—exchange and SOC—with superconducting coherence has already been demonstrated to lead to unique signatures in spectroscopy and transport, and is furthermore expected to induce topological superconductivity hosting Majorana states. In this theory talk, we will focus on the most intriguing transport ramifications of SOC in superconducting magnetic junctions, covering giant transport magnetoanisotropies in the junctions' conductance and Josephson-current flow [1], the possibility to generate sizable transverse anomalous (Josephson) Hall effects [2,3], as well as nonreciprocal transport and supercurrent-diode characteristics in proximitized 2DEG Josephson junctions [4] that were experimentally classified through robust Josephson-inductance measurements.

This work was supported by ENB IDK Top. Insulators, DFG SFB 1277 (B07), and DFG Grant 454646522.

[1] PRB 95, 024514 (2017)
[2] PRB 100, 060507(R) (2019)
[3] PRB 101, 104508 (2020)
[4] Nat. Nanotechnol. (2021)

TT 26.11 Thu 12:15 H10

Non-equilibrium transport in Josephson junctions through interacting nanostructures — •Jordi Picó Cortés[1,2], Gloria Platero[2], and Milena Grifoni[1] — [1]Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany — [2]Instituto de Ciencia de Materiales de Madrid (CSIC) E-28049, Spain

Studying transport through interacting nanostructures is challenging due to the interplay between strong interactions and the coupling to large thermalized leads. In the case of superconducting leads, this is further complicated by a number of features particular to Josephson junctions, chiefly the effect of Cooper pairs and the resulting anomalous transport. In this work, we develop a diagrammatic approach to transport through weakly coupled Josephson junctions [1,2,3] which treats the interaction inside the dot exactly and employ it to describe the conventional and Josephson currents. The dynamics of Cooper pairs out of equilibrium are described in a particle-conserving formalism, which avoids issues arising from the usual BCS treatment, allowing us to extend the description of electron pairing inside the dot and the $0-\pi$ transition beyond the usual equilibrium treatment.

[1] M. Governale, M.G. Pala, J. König, Phys. Rev. B 77, 134513 (2008)
[2] B. Hiltscher, M. Governale, J. König, Physical Review B 86, 235427 (2012)
[3] J. Siegl, J. Picó-Cortés, M. Grifoni, arXiv:2205.13936 (2022)

TT 26.12 Thu 12:30 H10

Interplay of Cooper pair and quasiparticle tunneling in the dynamics of an Anderson pseudospin — •Christoph Rohrmeier, Jordi Picó-Cortés, Andrea Donarini, and Milena Grifoni — Institute of Theoretical Physics, University of Regensburg, Germany

In an interacting quantum dot coupled to superconducting reservoirs, the state of the system can be described in terms of a pseudospin [1] where "up" represents a fully occupied and "down" means an empty dot [2]. We investigate the dynamics of this Anderson pseudospin with the help of a generalized master equation based on a particle-conserving approach to superconductivity [3]. Superconducting correlations involved in Cooper pair and quasiparticle tunneling manifest in the pseudospin dynamics. The pseudospin precession is governed by an effective magnetic field [4] of which we give an analytical expression including finite gap, bias as well as interaction.

[1] P. Anderson, Phys. Rev. 112, 1900 (1958)
[2] M. Governale, M. Pala, Jürgen König, Phys. Rev. B 77, 134513 (2008)
[3] J. Siegl, J. Picó-Cortés, M. Grifoni, arXiv:2205.13936 (2022)
[4] C. Rohrmeier and A. Donarini, Phys. Rev. B 105, 205418 (2022)

TT 26.13 Thu 12:45 H10

Evolution of Andreev bands in half-filled superconducting periodic Anderson model — •Vladislav Pokorny[1] and Panch Ram[2] — [1]Institute of Physics, Czech Academy of Sciences, Na Slovance 2, CZ-18221 Praha 8, Czech Republic — [2]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, CZ-12116 Praha 2, Czech Republic

Two-dimensional systems where the surface of a superconductor is coated with a molecular layer draw recently a lot of attention as they represent ideal setups for studying the competition between magnetism and superconductivity. The physics of such system can be studied using the superconducting periodic Anderson model which describes a conduction band with superconducting pairing hybridized with a non-dispersive band of correlated electrons. We use the dynamical mean-field theory to solve this problem by mapping the lattice model to the superconducting impurity Anderson model with a self-consistent bath. This method neglects spatial correlations between lattice sites while local quantum fluctuations are fully taken into account. We show the behavior of the in-gap Andreev bands and how the singlet-doublet (zero-pi) quantum phase transition in the impurity model is reflected in the induced pairing in the correlated band.

TT 27: Quantum Coherence and Quantum Information Systems (joint session TT/DY)

Time: Thursday 9:30–12:30 Location: H22

TT 27.1 Thu 9:30 H22

Design of a granular aluminum Fluxonium qubit in a coplanar waveguide architecture — •Patrick Paluch, Martin Spiecker, Nicolas Gosling, Alexandru Ionita, Simon Günzler, Daria Gusenkova, Dennis Rieger, Ivan Takmakov, Francesco Valenti, Patrick Winkel, Wolfgang Wernsdorfer, and Ioan-Mihai Pop — Karlsruhe Institute of Technology

Fluxonium qubits are often embedded in rectangular waveguides which dilute the electric field and favor high coherence [1,2]. However, this configuration complicates in-situ flux gates and multi-qubit experiments. Here, we present a fluxonium qubit placed in a coplanar waveguide architecture with an integrated fast-flux coil, surrounded by a normal metal ground plane. The superinductor is made out of granular aluminum (grAl) [3] and the use of a comparably large silver ground plane potentially decreases the number of quasiparticles in the system via phonon trapping [4].

[1] Pop et al., Nature 508, 369 (2014)
[2] Somoroff et al., arXiv:2103.08578 (2021)
[3] Grünhaupt et al., Nat. Mater. 18, 816 (2019)
[4] Henriques et al., Appl. Phys. Lett. 115, 212601 (2019)

TT 27.2 Thu 9:45 H22

Gralmonium: Granular aluminum nano-junction Fluxonium qubit — •Dennis Rieger, Simon Günzler, Martin Spiecker, Patrick Paluch, Patrick Winkel, Lothar Hahn, Judith K. Hohmann, Andreas Bacher, Wolfgang Wernsdorfer, and Ioan M. Pop — Karlsruhe Institute of Technology, Germany

Mesoscopic Josephson junctions (JJs), consisting of overlapping superconducting electrodes separated by a nanometer thin oxide layer, provide a precious source of nonlinearity for superconducting quantum circuits and are at the heart of state-of-the-art qubits, such as the transmon and fluxonium. Here, we show that in a fluxonium qubit the role of the JJ can also be played by a lithographically defined, self-structured granular aluminum (grAl) nano-junction: a superconductor-insulator-superconductor (SIS) JJ obtained in a single layer, zero-angle evaporation. The measured spectrum of the resulting qubit, which we nickname gralmonium, is indistinguishable from the one of a standard fluxonium qubit. Remarkably, the lack of a mesoscopic parallel plate capacitor gives rise to an intrinsically large grAl nano-junction charging energy in the range of $10-100\,\mathrm{GHz}$, comparable to its Josephson energy E_J. We measure average energy relaxation times of $T_1 = 10\,\mu s$ and Hahn echo coherence times of $T_2^{\mathrm{echo}} = 9 \mu s$. The exponential sensitivity of the gralmonium to the E_J of the grAl nano-junction provides a highly susceptible detector. Indeed, we observe spontaneous jumps of the value of E_J on timescales from milliseconds to days, which offer a powerful diagnostics tool for microscopic defects in superconducting materials.

TT 27.3 Thu 10:00 H22

Quantum dynamics of disordered arrays of interacting superconducting qubits: Signatures of quantum collective states — Mikhail Fistul, •Oliver Neyenhuys, Antonia Bocaz, and Ilya Eremin — Theoretische Physik III, Ruhr-Universität Bochum, Bochum 44801, Germany

We study theoretically the collective quantum dynamics occurring in various interacting superconducting qubits arrays (SQAs) in the presence of a spread of individual qubit frequencies. The interaction is provided by mutual inductive coupling between adjacent qubits (short-range Ising interaction) or inductive coupling to a low-dissipative resonator (long-range exchange interaction). In the absence of interaction the Fourier transform of the temporal correlation function of the total polarization (z-projection of the total spin), i.e. the dynamic susceptibility $C(\omega)$, demonstrates a set of sharp small magnitude resonances corresponding to the transitions of individual superconducting qubits. We show that even a weak interaction between qubits can overcome the disorder with a simultaneous formation of the collective excited states. This collective behavior manifests itself by a single large resonance in $C(\omega)$. In the presence of a weak non-resonant microwave photon field in the low-dissipative resonator, the positions of dominant resonances depend on the number of photons, i.e. the collective ac Stark effect. Coupling of an SQA to the transmission line allows a straightforward experimental access of the collective states in microwave transmission experiments and, at the same time, to employ SQAs as sensitive single-photon detectors.

TT 27.4 Thu 10:15 H22

Heat transport and rectification in an ultrastrongly-coupled qubit-resonator system — •Luca Magazzu[1], Milena Grifoni[1], and Elisabetta Paladino[2] — [1]University of Regensburg — [2]University of Catania

Inspired by the recent experimental developments in the field of heat transport in the quantum regime, we consider a flux qubit coupled to a superconducting resonator as a composite open quantum system. The two elements of this open quantum Rabi system interact with two heat baths held at different temperatures. At the steady state, a heat current is established which is the result of photon exchanges between the system and the baths. Due to the geometry of the setup, the coupling to the heat baths is asymmetric. In turn this entails the presence of a preferred direction for the heat current, to a degree quantified by the heat rectification.

We calculate the heat current and rectification in different coupling regimes and considering a periodic driving applied to the qubit. The rectification displays the signatures of multi-photon processes that occur when the qubit-resonator coupling enters the nonperturbative regime

[1] A. Ronzani et al., Nat. Phys. 14, 991 (2018)
[2] J. Senior, A. Gubaydullin, B. Karimi, J. T. Peltonen, J. Ankerhold, J. P. Pekola, Commun. Phys. 3, 40 (2020)
[3] B. Bhandari, P. Andrea Erdman, R. Fazio, E. Paladino, and F. Taddei. Phys. Rev. B 103, 155434 (2021)
[4] L. Tesser, B. Bhandari, P. A. Erdman, R. Fazio, E. Paladino, F. Taddei, New J. Phys. 24, 035001 (2022)

TT 27.5 Thu 10:30 H22

Probing the coherence of superconducting Fluxmon qubits — •Benedikt Berlitz, Alexander Neumann, Alexander Bilmes, Jürgen Lisenfeld, and Alexey V. Ustinov — Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

The Fluxmon qubit combines a transmission line resonator with a DC-SQUID and offers wide control over the circuit's potential energy via two independently applied bias flux channels. This allows one to operate the qubit as a phase or flux qubit, provides means for fast single-shot qubit readout, and offers a path to characterize decoherence due to surface spins and tunneling defects in a wide frequency range. We will review the Fluxmon qubit design and fabrication, and present measurements of its potential energy landscape which demonstrate single- and double well qubit physics. Our time-resolved measurements confirm that the Fluxmon qubit's performance is strongly limited by microscopic sources of decoherence, which might render it a suitable detector for defect spectroscopy applications.

TT 27.6 Thu 10:45 H22

Mapping the positions of individual material defects in superconducting transmon qubits — •Alexander K. Händel, Benedikt Berlitz, Alexander Bilmes, Jürgen Lisenfeld, and Alexey V. Ustinov — Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

In superconducting quantum bits, material defects at the surface of circuit electrodes and the substrate constitute a major source of decoherence. In our experiment, we detect individual defects with a transmon qubit while tuning their resonance frequencies with applied static electric fields. We fabricated samples that feature on-chip gate electrodes that are placed close to the qubit island. By measuring the coupling strength of each detected defect to various electrodes, we are able to deduce the defect's position on the qubit chip. Our goal is to create two-dimensional maps of defect distribution over qubit electrodes. This will help to identify circuit components which contain majority of coherence-breaking defects and improve fabrication methods towards more coherent qubits.

15 min. break

TT 27.7 Thu 11:15 H22

Quantum memory based on spin donors in silicon — •Patricia Oehrl[1,2], Julian Franz[1,2], Florian Fesquet[1,2], Nadezhda Kukharchyk[1,2], Kirill G. Fedorov[1,2], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [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 Technologies (MCQST), Germany

Quantum memories are considered as key elements for the successful realization of quantum communication [1]. In order to allow for the connection of several quantum nodes into a quantum network without frequency conversion, several requirements have to be met such as frequency compatibility and connectability to the quantum system of choice. As superconducting quantum processors operate in the microwave regime, solid-state spin ensembles with their exceptional coherence times are promising candidates [2]. Here, we present a hybrid system consisting of a superconducting lumped-element microwave resonator coupled to a phosphorus donor electron spin ensemble hosted in isotopically engineered silicon. We present experimental results on the storage of coherent microwave states and their retrieval using a Hahn-echo type pulse sequence. In detail, we discuss the impact of the resonator design, the classical storage times and outline strategies towards storing quantum signals.

We acknowledge financial support from the Federal Ministry of Education and Research of Germany (project number 16KISQ036).

[1] H. J. Kimble, Nature **453**, 1023 (2008)
[2] C. Gezes *et al.*, Phys. Rev. X **4**, 021049 (2014)

TT 27.8 Thu 11:30 H22

Crystal electric field effects in yttrium orthosilicate doped with paramagnetic rare-earth ions — •Tim Hofmann, Andreas Bauer, Fabian Kessler, and Christian Pfleiderer — Chair for the Topology of Correlated Systems, Department of Physics, Technical University of Munich, Germany

Monoclinic yttrium orthosilicate Y_2SiO_5 doped with several ten ppm of rare-earth ions, such as Er^{3+}, Yb^{3+}, or Nd^{3+}, represents a candidate material for optical applications in quantum information technology. The amount of dopants directly influences key properties, such as the linewidth or the coherence time, and in turn precise control on the doping levels is essential. The quantitative determination of doping on ppm level is challenging when using conventional characterization techniques. Here, we report the magnetic characterization of rare-earth doped yttrium orthosilicate single crystals. We infer information from magnetization measurements at low temperatures down to 2 K for magnetic fields up to 14 T applied along the optical axes b, $D1$, and $D2$, exhibiting paramagnetic contributions characteristic of rare-earth ions. Distinct crystalline anisotropy and the substitution of yttrium on two magnetically inequivalent sites is observed, indicating the importance of crystal electric field effects for both the fundamental characterization and potential applications in quantum information technology.

TT 27.9 Thu 11:45 H22

Synchronized coherent charge oscillations in coupled double quantum dots — •Eric Kleinherbers[1], Philipp Stegmann[2], and Jürgen König[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, 47057 Duisburg, Germany — [2]Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

We study coherent charge oscillations in double quantum dots tunnel-coupled to metallic leads [1]. If two such systems are coupled by Coulomb interaction, there are in total six (instead of only two) oscillation modes of the entangled system with interaction-dependent oscillation frequencies. By tuning the bias voltage, one can engineer decoherence such that only one of the six modes, in which the charge oscillations in both double quantum dots become synchronized in antiphase, is singled out. We suggest to use waiting-time distributions and the $g^{(2)}$-correlation function to detect the common frequency and the phase locking.

[1] E. Kleinherbers et al., Phys. Rev. B 104, 165304 (2021)

TT 27.10 Thu 12:00 H22

Electrically driven spin resonance with bichromatic driving — •Zoltán György[1], András Pályi[2], and Gábor Széchenyi[1] — [1]Institute of Physics, Eötvös University, H-1117 Budapest, Hungary — [2]Department of Theoretical Physics, Institute of Physics, Budapest University of Technology and Economics, H-1111 Budapest, Hungary

Electrically driven spin resonance (EDSR) is an established tool for controlling semiconductor spin qubits. Here, we theoretically study a frequency-mixing variant of EDSR, where two driving tones with different drive frequencies are applied, and the resonance condition connects the spin Larmor frequency with the sum of the two drive frequencies. Focusing on flopping-mode operation, we calculate the parameter dependence of the Rabi frequency and the Bloch-Siegert shift. A shared-control spin qubit architecture could benefit from this bichromatic EDSR scheme, as it enables simultaneous single-qubit gates.

TT 27.11 Thu 12:15 H22

Cavity-mediated superconductor-ferromagnet interaction — Andreas T. G. Janssønn, •Henning G. Hugdal, Arne Brataas, and Sol H. Jacobsen — Center for Quantum Spintronics, Department of Physics, NTNU, Norwegian University of Science and Technology, Trondheim, Norway

We present a microscopic theoretical analysis of interactions between a ferromagnet (FM) and superconductor (SC) mediated by photons in a cavity. This facilitates interactions over macroscopic distances, in contrast with extensively researched FM-SC proximity systems, and ensures there is no interfacial suppression of their respective order parameters. The spatial separation between the materials also means the FM and SC may be held at different temperatures, and has potential applications as a bridge in spintronic-superconducting circuitry. Specifically, we deduce the anisotropy field induced across the FM due to the presence of the SC when the system is subjected to a symmetry-breaking external field. Other quantities such as renormalized dispersion relations can also be deduced. The model is a modification and quantum mechanical extension of the principle presented in Janssøn et al. PRB 102, 180506(R) (2020).

TT 28: Correlated Electrons: Theory 1

Time: Thursday 9:30–13:00 Location: H23

TT 28.1 Thu 9:30 H23

General super-exchange Hamiltonians for magnetic and orbital physics in e_g and t_{2g} systems — •Xuejing Zhang[1], Erik Koch[1,2], and Eva Pavarini[1,2] — [1]Institute for Advanced Simulation, Forschungszentrum Jülich, D-52425 Jülich, Germany — [2]JARA High-Performance Computing, 52062, Aachen, Germany

In strongly-correlated transition-metal oxides, spin- and orbital-ordering or spin- and orbital-liquid phenomena are often studied with low-energy super-exchange Hamiltonians, derived from multi-band Hubbard models in highly symmetric cases and in the basis of pseudo-spin operators. This captures the essence of the Kugel-Khomskii[1] super-exchange mechanism. Recently, via an irreducible-tensor operator representation, we derived the orbital super-exchange Hamiltonian for t^1_{2g} perovskites and successfully used it, in combination with many-body calculations based on dynamical mean-field theory, to explain the orbital physics in these systems. Then, we generalize our method to e^n_g and t^n_{2g} systems at arbitrary integer filling n, including both spin and orbital interactions[2,3]. Here, we identified the t^2_{2g} perovskite $LaVO_3$ as a rare case in which orbital-ordering is indeed controlled by the KK super-exchange interaction[4].

[1] K. I. Kugel' and D. I. Khomskii, Zh. Eksp. Teor. Fiz. **64**, 1429 (1973) [Sov. Phys. JETP **37**, 725 (1973)]
[2] X. J. Zhang, E. Koch, E. Pavarini, Phys. Rev. B **102**, 035113 (2020)
[3] X. J. Zhang, E. Koch, E. Pavarini, Phys. Rev. B **105**, 115104 (2022)
[3] X. J. Zhang, E. Koch, and E. Pavarini, Submitted to Phys. Rev. Lett.

TT 28.2 Thu 9:45 H23

Fluctuations analysis of the spin susceptibility: Néel ordering revisited in dynamical mean field theory — •Georg Rohringer[1] and Lorenzo Del Re[2] — [1]Institute of Theoretical Physic, University of Hamburg, 20355 Hamburg, Germany — [2]Department of Physics, Georgetown University, 37th and O Sts., NW, Washington, DC 20057, USA

We revisit the antiferromagnetic (AF) phase diagram of the single-band three-dimensional Hubbard model on a simple cubic lattice studied within the dynamical mean field theory. Although this problem has been investigated extensively in the literature, a comprehensive understanding of the impact of the different one- and, in particular, two-particle local correlation functions of DMFT on the AF transition temperature is still missing. We have, hence, performed a fluctuation analysis of T_N with respect to different local bosonic fluctuations (charge, spin, particle-particle) contained in the two-particle vertex of DMFT. Our results indicate that, beyond weak coupling, the screening of the DMFT vertex by local fluctuations leads to an enhancement of T_N with respect to a random phase approximation (RPA) like calculation where this vertex is replaced by the bare interaction. The overall suppression of T_N in DMFT with respect to RPA is then solely due to the incoherence introduced by the DMFT self-energy in the one-particle Green's functions. This illustrates the Janus-faced role of the local moment formation in the DMFT solution of the Hubbard model, which leads to completely opposite effects in the one- and two-particle correlation functions.

TT 28.3 Thu 10:00 H23

Phase diagram of SU(N) antiferromagnet on a square lattice — •Jonas Schwab, Francesco Parisen Toldin, and Fakher F. Assaad — Institut für Theoretische Physik und Astrophysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany

We investigate the ground state phase diagram of an antiferromagnetic, SU(N)-symmetric spin model on a square lattice, where the chosen irreducible representation of the $\mathfrak{su}(N)$ algebra is described by a square Young tableaux with $N/2$ rows and $2S$ columns. Using approximation-free fermionic quantum Monte Carlo simulations for $S \in \{1/2, 1, 3/2\}$ and even values of N in the range $N \in [2, 20]$, we present a phase diagram for this model. Our results are in line with the seminal work of Read and Sachdev. For any value S, we find Néel order at small values of N, and disordered valence-bond solid (VBS) states at large N. The degeneracy of the VBS state, 4 for $S = 1/2$ and 3/2 and 2 for $S = 1$, close to the Néel state follows the lower bound obtained by analyzing monopole singularities in the large-S limit. In contrast in the large-N limit, the VBS ground state shows a four fold degeneracy for all values of S. In order to best image the dimerization patterns, so as to confirm the above, we use a pinning field approach.

TT 28.4 Thu 10:15 H23

Field-tunable Berezinskii-Kosterlitz-Thouless correlations in a quasi-2d spin-1/2 Heisenberg lattice — D. Opherden[1], M.S.J. Tepaske[2,3], F. Bärtl[1,4], M. Weber[3], M.M. Turnbull[5], T. Lancaster[6], S.J. Blundell[7], M. Baenitz[8], J. Wosnitza[1,4], C.P. Landee[9], R. Moessner[3], D.J. Luitz[2,3], and •H. Kühne[1] — [1]Hochfeld-Magnetlabor Dresden, HZDR — [2]Physikalisches Institut, Univ. Bonn — [3]MPI PKS, Dresden — [4]IFMP, TU Dresden — [5]Carlson School of Chemistry, Clark Univ. — [6]Durham Univ., Centre for Materials Physics — [7]Clarendon Laboratory, Univ. of Oxford — [8]MPI CPfS, Dresden — [9]Department of Physics, Clark Univ.

We discuss the manifestation of field-induced Berezinskii-Kosterlitz-Thouless (BKT) correlations in the weakly-coupled spin-1/2 Heisenberg layers of the material $[Cu(pz)_2(2\text{-}HOpy)_2](PF_6)_2$ (CuPOF). Due to the moderate intralayer exchange coupling of $J/k_B = 6.8$ K, laboratory magnetic fields induce a substantial XY anisotropy of the spin correlations. This provides a significant BKT regime, as the tiny interlayer exchange $J'/k_B \approx 1$ mK only induces 3d correlations upon close approach to the BKT transition. We employed NMR and μ^+SR measurements to probe the spin correlations that determine the critical temperatures of the long-range order and the BKT transition. Further, we performed stochastic series expansion QMC simulations based on the experimentally determined model parameters. Finite-size scaling of the spin stiffness yields an excellent agreement of the critical temperatures between theory and experiment.

Invited Talk TT 28.5 Thu 10:30 H23

Towards an *ab-initio* theory of Anderson localization for correlated electrons — •Liviu Chioncel — University of Augsburg, Augsburg, Germany

Great progress has been made in recent years towards understanding the properties of disordered electronic systems. This is made possible by recent advances in quantum effective medium methods which include Dynamical Mean-Field Theory and the Coherent Potential Approximation, and their cluster extension, the Dynamical Cluster Approximation. The recently developed typical medium dynamical cluster approximation captures disorder-induced localization and provides an order parameter for the Anderson localized states. We present an overview of various recent applications of the typical medium single-site and dynamical cluster approximation to the Hubbard model, and its combination to realistic systems in the framework of Density Functional Theory.

15 min. break

TT 28.6 Thu 11:15 H23

The crucial influence of side groups on magnetic superexchange - a modification of the Goodenough-Kanamori-rules — Dijana Milosavljevic[1], Oleg Janson[2], Stefan-Ludwig Drechsler[2], and •Helge Rosner[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, 01187 Dresden, Germany — [2]IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany

According to the famous Goodenough-Kanamori-Anderson rules, the key structural feature that determines the magnetic exchange coupling constant for superexchange in magnetic insulators is the magnetic ion-ligand-magnetic ion bond angle. Here, we demonstrate that this angle is not the only factor. An at least equally important influence on the exchange coupling has the presence of the side groups attached to the ligands. Applying density functional calculations and subsequently derived realistic parameters for a multiband model tight-binding model, we provide a quantitative analysis for the example case of edge-sharing Cu-O chains with bond angles near 90 degrees. We find that a single parameter, the difference in onsite energies of the ligand orbitals parallel and perpendicular to the Cu-O chain, is at least as important as the bond angle for sign and size of the superexchange. This parameter strongly depends on the position of side groups outside the superexchange pathway. For a fixed bond angle, changes of a side group position, only, can cause changes in the superexchange of several hundred Kelvin and thus dramatic changes in the magnetic ground state.

TT 28.7 Thu 11:30 H23

The shared universality of charged black holes and the many many-body SYK model — •Jan Louw — Institute for Theoretical Physics, Georg-August-Universität Goettingen, Friedrich-Hund-Platz 1, 37077 Goettingen, Germany

We investigate the charged q/2-body interacting Sachdev-Ye-Kitaev (SYK) model in the grand-canonical ensemble. By treating q as a large parameter, we are able to analytically study its phase diagram. By varying the chemical potential or temperature, we find that the system undergoes a phase transition between low and high entropies, in the maximally chaotic regime. A similar transition in entropy is seen in charged AdS black holes transitioning between a large and small event horizon. Approaching zero temperature, we find a first-order chaotic-to-integrable quantum phase transition, where the finite extensive entropy drops to zero. This again has a gravitational analogue–the Hawking-Page (HP) transition between a large black hole and thermal radiation. An analytical study of the critical phenomena associated with the continuous phase transition provides us with two sets of critical exponents. These sets define two separate universality classes, both of which include several charged AdS black hole phase-transitions. Together, these findings indicate a connection between the charged large q SYK model and black holes.

TT 28.8 Thu 11:45 H23

Scrambling and Many-Body Localization in the XXZ-Chain — •Niklas Bölter and Stefan Kehrein — Institut für Theoretische Physik, Universität Göttingen

The tripartite information is an observable-independent measure for scrambling and delocalization of information. Therefore one can expect that the tripartite information is a good observable-independent indicator for distinguishing between many-body localized and delocalized regimes, which we confirm for the XXZ-chain in a random field. Specifically, we find that the tripartite information signal spreads inside a lightcone that only grows logarithmically in time in the many-body localized regime similar to the entanglement entropy. We also find that the tripartite information eventually reaches a plateau with an asymptotic value that is suppressed by strong disorder.

[1] N. Bölter and S. Kehrein, Phys. Rev. B 105, 104202

TT 28.9 Thu 12:00 H23

Nonlinear response theory and three-particle diagrams in strongly correlated systems — •Patrick Kappl, Friedrich Krien, Clemens Watzenböck, and Karsten Held — Institute of Solid State Physics, TU Wien, Austria

We study three-particle correlation functions of the Anderson impurity model by means of quantum Monte Carlo simulations in the hybridization expansion. We analyze the parameter regime in which vertex corrections beyond the bare bubble term become relevant for the three-particle correlator. Such three-particle correlators are hitherto by-and-large terra incognita and become relevant for the next level of diagrammatic extensions of dynamical mean-field theory. We here restrict ourselves to correlators consisting of three densities n and spins $S_{x,y,z}$. These are related to nonlinear response theory and its zero-frequency component to the density-dependence of the electronic compressibility.

TT 28.10 Thu 12:15 H23

Superconductivity in 2D and 3D lattice models of correlated fermions - combining matrix-product states with mean-field theory — Gunnar Bollmark[1], Svenja Marten[2], •Thomas Köhler[1], Lorenzo Pizzino[3], Yiqi Yang[4], Johannes-Stephan Hofmann[5], Hao Shi[6], Shiwei Zhang[7], Salvatore R. Manmana[2], Thierry Giamarchi[3], and Adrian Kantian[1,8] — [1]Uppsala University, Sweden — [2]Georg-August-Universität Göttingen, Germany — [3]University of Geneva, Switzerland — [4]College of William and Mary, Williamsburg, Virginia, USA — [5]Weizmann Institute of Science, Rehovot, Israel — [6]University of Delaware, Newark, USA — [7]Flatiron Institute, New York, USA — [8]Heriot-Watt University, Edinburgh, United Kingdom

Correlated electron states are at the root of many important phenomena including unconventional superconductivity (USC), where electron-pairing arises from repulsive interactions. Computing the properties of correlated electrons, such as the critical temperature Tc for the onset of USC, efficiently and unbiased remains a major challenge. Here, we combine matrix-product states (MPS) with static mean field (MF) to provide a solution to this challenge for 2D/3D materials comprised of weakly coupled correlated chains. This framework of Q1D fermions is developed and validated for attractive Hubbard systems and further enhanced via analytical field theory. Finally, we investigate the formation of transient non-equilibrum SC by a real-time evolution of a 3D extended Hubbard system out-of-equilibrium.

TT 28.11 Thu 12:30 H23

Non-local correlations and criticality in the triangular lattice Hubbard model — •Mario Malcolms de Oliveira[1], Julian Stobbe[2], Henry Menke[3], Marcel Klett[1], Georg Rohringer[2], and Thomas Schäfer[1] — [1]Max Planck Institute for Solid State Research — [2]University of Hamburg — [3]University of Erlangen-Nuremberg

We investigate the role of non-local electronic correlations at finite temperatures in the half-filled triangular lattice Hubbard model using the dynamical vertex approximation (DΓA), a diagrammatic extension [1] of the dynamical mean-field theory (DMFT). We analyze the impact of (quantum) phase transitions on finite temperature properties at the one- and two-particle level. We discuss the absence of magnetic ordering at finite temperatures due to the fulfilment of the Mermin-Wagner theorem and the (Mott) metal-insulator crossover. In addition we compare the results of this method to the ones obtained by other cutting-edge techniques like DMFT, its real-space cluster extension cellular dynamical mean-field theory (CDMFT) and diagrammatic Monte Carlo (DiagMC) [2].

[1] G. Rohringer, H. Hafermann, A. Toschi, A.A. Katanin, A.E. Antipov, M.I. Katsnelson, A.I. Lichtenstein, A.N. Rubtsov, K. Held, Rev. Mod. Phys. 90, 025003 (2018)
[2] A. Wietek, R. Rossi, F. Šimkovic IV, M. Klett, P. Hansmann, M. Ferrero, E.M. Stoudenmire, T. Schäfer, A. Georges, Phys. Rev. X 11, 041013 (2021)

TT 28.12 Thu 12:45 H23

Non-local correlation and entanglement of ultracold bosons in the two-dimensional Bose-Hubbard lattice at finite temperature — Ulli Pohl, •Sayak Ray, and Johann Kroha — Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn, Nußallee 12, 53115, Bonn, Germany

The temperature-dependent behavior emerging in the vicinity of the superfluid (SF) to Mott-insulator (MI) transition of interacting bosons in a 2D optical lattice, described by the Bose-Hubbard model is investigated. The equilibrium phase diagram at finite temperature is computed using the cluster mean-field (CMF) theory including a finite-cluster-size-scaling. The SF, MI, and normal fluid (NF) phases are characterized as well as the transition or crossover temperatures between them are estimated by computing physical quantities such as the superfluid fraction, compressibility and sound velocity using the CMF method. It is found that the nonlocal correlations included in a finite cluster, when extrapolated to infinite size, leads to quantitative agreement of the phase boundaries with quantum Monte Carlo results as well as with experiments. Moreover, it is shown that the von Neumann entanglement entropy within a cluster corresponds to the system's entropy density and that it is enhanced near the SF-MI quantum critical point (QCP) and at the SF-NF boundary. The behavior of the transition lines near this QCP, at and away from the particle-hole symmetric point located at the Mott-tip, is also discussed.

[1] U. Pohl, S. Ray, J. Kroha, Ann. Phys. (Berlin) 2100581 (2022)

TT 29: Transport: Poster Session

In case the presenters cannot be present at their posters for the full duration of the poster session, they are kindly requested to leave a note at their poster indicating when they will be available for discussion.

Time: Thursday 15:00–18:00 Location: P1

TT 29.1 Thu 15:00 P1

Relaxation dynamics in two quantum dots coupled to the environment: The role of coupling asymmetry — •Lukas Litzba, Eric Kleinherbers, Nikodem Szpak, and Jürgen König — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany

We study a strongly interacting two-site Fermi-Hubbard model representing two coupled quantum dots and couple them each with different strengths to Markovian baths. We start with the Born-Redfield equation (without second Markov approximation) and approximate it by the coherent Lindblad master equations [1]. Using this technique we observe that the long-time dynamics of a quantum state, in particular the contribution from the energy coherences, depends strongly on the asymmetry between the bath coupling strengths of the dots. In contrast to the Born-Redfield equation and the coherent Lindblad master equations the popular secular approximation fails to properly describe the interdot and bath-dot currents in the asymmetric coupling case. To compare the quality of the approximations we use the exact solution in the case of no Coulomb interaction.

[1] E. Kleinherbers, N. Szpak, J. König, R. Schützhold, Phys. Rev. B 101, 125131 (2020)

TT 29.2 Thu 15:00 P1

Manipulating molecular spins with carbon nanotube SQUIDs — •Tim Althuon, Aljoscha Auer, Tino Cubaynes, and Wolfgang Wernsdorfer — Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe

Single-molecule magnets (SMMs) are promising candidates for spin-qubits due to their small size, cheap and reproducible chemical synthesis in a bottom-up approach and the opportunity to engineer their chemical properties such as the magnetic moment. However, an integration of SMMs with nanoscale diameters into electronic circuits is challenging. A solution to this problem could be to graft these molecules on carbon nanotubes (CNTs) which are comparable to SMMs in the diameter and possess unique sensing properties.

The CNT can be included as a weak-link Josephson junction into a superconducting quantum interference device (SQUID). Such a nano-SQUID is expected to have a large coupling between the magnetic moment of a molecule grafted on the CNT and the flux through the SQUID loop, giving rise to a very simple and precise detection of the spin of a single molecule.

Our CNTs are grown on separate chips with chemical vapor deposition and can then be integrated into prepatterned electronic circuits. For this purpose we use a novel, ultraclean, dry-transfer technique of CNTs where the CNTs are never exposed to air. This contribution will mainly focus on the integration of suspended CNTs into electronic circuits including preliminary results on the characterization of the devices at room and milli-Kelvin temperatures.

TT 29.3 Thu 15:00 P1

A carbon-nanotube nanoelectromechanical system coupled to a single-molecule magnet — •Aljoscha Auer, Svenja Müller, Tim Althuon, Tino Cubaynes, and Wolfgang Wernsdorfer — Karlsruher Institut für Technologie, 76131 Karlsruhe

The one-dimensional structure of carbon nanotubes (CNTs) as well as their low weight and high Young*s modulus make them an excellent candidate for nanoelectromechanical systems (NEMS). With their mechanical resonance frequency in the hundreds of MHz regime combined with a large quality factor they are suited for high sensitivity experiments. In addition, the conductivity of CNTs can be tuned nicely by applying an electric field tuning the energy levels of charge carriers. For our experiments we want to use a suspended, top-down fabricated carbon nanotube, grown by chemical vapour deposition connecting two electrodes or using a stamping technique where the CNT is grown on a separate chip. Five local gates below the suspended nanotube enable us to manipulate the system by application of a tunable electric field. Furthermore, we want to attach a single-molecule magnet (SMM) to the nanotube by thermal evaporation, therefore creating a system using spin-phonon-coupling to address a single individual spin. The possible measurements in this configuration are manifold, ranging from magnetoresistive effects, spin valves respectively, and double quantum dot transport measurements to electron-phonon coupling measurable in transport measurements in a mechanical resonator.

TT 29.4 Thu 15:00 P1

Investigation of Hall effects in freestanding $SrRuO_3$ nanomembranes — •Stefan Petersen, Roman Hartmann, Elke Scheer, and Angelo Di Bernardo — University of Konstanz, Konstanz, Germany

$SrRuO_3$ (SRO) is a one of the most intensively studied ferromagnetic oxides with a Curie temperature of about 150 K. In addition to being ferromagnetic, SRO is also interesting because of its high conductivity at low temperatures, high chemical stability and good lattice matching with other oxides.

Recently, a new technique has been developed to manufacture freestanding nanomembranes of oxide thin films grown on a water-soluble $Sr_3Al_2O_6$ (SAO) sacrificial layer [1]. In our group, we have recently reproduced this process and been able to obtain freestanding nanomembranes of SRO.

We have investigated the anomalous Hall effect (AHE) and topological hall effect (THE) in SRO nanomembranes as a function of thickness and temperature, using SRO thin films grown on $SrTiO_3$ substrates as benchmark for comparison. We have also studied the evolution of these effects in SRO nanomembranes under a voltage-driven strain exerted by a piezoelectric substrate in contact with the nanomembrane. Our results are preliminary to the fabrication of devices with electric control of the AHE and THE.

[1] D. Lu et al., Nat. Mater. 15, 1255 (2016)

TT 29.5 Thu 15:00 P1

Curvature control of the superconducting proximity effect in diffusive ferromagnetic nanowires — •Tancredi Salamone[1], Henning Hugdal[1], Morten Amundsen[2], and Sol Jacobsen[1] — [1]QuSpin Center for Quantum Spintronics, NTNU, Trondheim, Norway — [2]Nordita, KTH Royal Institute of Technology, Stockholm, Sweden

There is currently great interest in the inclusion of superconducting components in spintronic devices, because they can provide dissipationless currents, greatly enhancing device performances for spin-based data processing. Coupling a conventional s-wave superconductor to a ferromagnet allows, via the proximity effect, to generate superconducting triplet correlations. The generation of triplet correlations can be employed to achieve a superconducting triplet spin-valve effect in superconductor-ferromagnet (SF) hybrid structures, for example by switching the magnetizations of the ferromagnets between parallel and antiparallel configurations in F_1SF_2 and SF_1F_2 trilayers, or in SF bilayers with both Rashba and Dresselhaus spin-orbit coupling. It was recently reported that geometric curvature can control the generation of long ranged triplets [1]. In our most recent work [2], we use this feature to show that the superconducting critical temperature of the hybrid structure can be tuned by varying the curvature of the ferromagnetic wire alone, with no need of another ferromagnet or SOC. Furthermore, we show that the variation of the critical temperature as a function of the curvature can be exploited to obtain a robust, curvature-controlled, superconducting triplet spin-valve effect.

[1] Phys. Rev. B **104**, L060505
[2] Phys. Rev. B **105**, 134511

TT 29.6 Thu 15:00 P1

Electronic transport through single-molecule junctions of photoswitchable diarylethenes — •Valentin Barth[1], Lukas Holz[1], Thomas Huhn[1], Franz Herbst[1], Gautam Mitra[1], Christopher Weaver[2], Sergii Snegir[1], Tim Albrecht[2], and Elke Scheer[1] — [1]University of Konstanz, Konstanz, Germany — [2]University of Birmingham, Birmingham, UK

Single-molecule junctions represent the conceptually simplest molecular devices. It is important to determine their electronic transport properties. Here we report on the transport characteristics of diarylethene-oligophenylene (DAE-OPE) molecule junctions at room and low temperature [1]. DAE molecules exist in two distinct stable states switched by irradiation of either visible or UV-light. Measurements are executed with the mechanically controllable break junction (MCBJ) method. Connection between the molecule and the gold electrodes is achieved by thiol end groups. The aim of the project is to distinguish the two states by their electrical transport properties. For this purpose, conductance histograms and current-voltage curves are measured separately for both states and compared afterwards. At room temperature, the conductance histograms of the states show small differences. These can be highlighted with the help of dimension reduction methods and neural networks [2]. Molecular vibration modes and thereby the current pathway through the molecule are determined for both states, by Inelastic electron tunneling spectroscopy (IETS).

[1] Sendler et al., Adv. Sci. 2 (2015) 1500017
[2] Albrecht et al., Nanotechnology 28 (2017) 423001

TT 29.7 Thu 15:00 P1

Low-temperature contact engineering for MoS_2 microtubes

— •Jonathan Neuwald[1], Robin T. K. Schock[1], Matthias Kronseder[1], Wolfgang Möckel[1], Simon Reinhardt[1], Luka Pirker[2], Maja Remškar[2], and Andreas K. Hüttel[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Solid State Physics Department, Institute Jožef Stefan,1000 Ljubljana, Slovenia

Planar molybdenum disulphide MoS_2, a 2d material similar to graphene, displays a multitude of interesting electronic properties. Nevertheless, only few electronic experiments on MoS_2 nanotubes and microtubes exist. A central reason for this is the difficulty of obtaining stable and transparent Ohmic contacts to transition metal dichalcogenides in general. At the metal-semiconductor interface, the Fermi level in MoS_2 is typically strongly pinned close to the conduction band edge. To avoid a high contact resistance from the formation of a Schottky-barrier, low-work function metals have to be chosen. However, these etch into the MoS_2 structure and therefore damage the tube. Following a recent publication,[1] we use the half-metal bismuth as a contact material, which disables the Fermi level pinning. We optimize the bismuth layer thickness to lower contact resistance and therefore improve the controllability and clarity of transport effects at millikelvin temperatures.

[1] P.C. Shen *et al.*, Nature 593, **211** (2021)

TT 29.8 Thu 15:00 P1

Andreev reflection in gated bilayer graphene

— •Panch Ram[1], Detlef Beckmann[2], Romain Danneau[2], and Wolfgang Belzig[1] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, D-76021 Karlsruhe, Germany

In this poster, we will present our recent theoretical study of the NS junction Andreev reflection and differential conductance on the bilayer graphene including different (equal and opposite) onsite potential for each monolayer graphene. We employ the Dirac-Bogoliubov de Gennes (DBdG) equation for the low-energy bilayer graphene Hamiltonian and calculate the Andreev reflection (retroreflection as well as specular) and differential conductance (within the Blonder-Tinkham-Klapwijk formalism [1-2]) for the junction in two different parameters limits: (i) interlayer coupling is larger energy scale (ii) superconducting-side doping potential is larger energy scale [3-5]. We obtain the Andreev retroreflection (specular reflection) below (above) the normal-side Fermi energy when the bias voltage is less than the superconducting gap. We also observe that both retro and specular Andreev reflections are strongly modified by the gate field.

[1] A. F. Andreev, Sov. Phys. JETP 19, 1228 (1964)
[2] G. E. Blonder et. al, Phys. Rev. B 25, 4515 (1984)
[3] C. W. J. Beenakker, Phys. Rev. Lett. 97, 067007 (2006)
[4] T. Ludwig, Phys. Rev. B 75, 195322 (2007)
[5] D. K. Efetov and K. B. Efetov, Phys. Rev. B 94, 075403 (2016)

TT 29.9 Thu 15:00 P1

Coulomb blockade effects in minimally twisted bilayer graphene

— •Patrick Wittig[1], Fernando Dominguez[1], Cristophe De Beule[2], and Patrik Recher[1,3] — [1]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg — [3]Laboratory of Emerging Nanometrology, 38106 Braunschweig, Germany

In the presence of a finite interlayer electric field, minimally twisted bilayer graphene displays a triangular network of chiral valley Hall states that propagate along the AB/BA interfaces and scatter at the metallic AA regions. Previous studies model the chiral network using a phenomenological scattering matrix approach based entirely on the symmetries of the system. So far, the physics of the metallic AA scattering regions has been disregarded, and indeed, the finite size of the AA regions (order of nm) can give rise to similar physics as quantum dots: a discrete energy spectrum and also interacting effects such as Coulomb blockade physics. In our contribution, we include these effects and study the resulting network of chiral modes and quantum dots through the energy spectrum and magneto-conductance calculations.

TT 29.10 Thu 15:00 P1

Interaction effects in graphene/2D polymer heterostructures

— •Francesca Falorsi[1], Kejun Liu[2], Miroslav Polozij[2], Christian Eckel[1], Thomas Heine[2], Xinliang Feng[2], Renhao Dong[2], and Thomas Weitz[1] — [1]I. Physical Institute -Georg-August-University, Friedrich-Hund-Platz 1 37077 Göttingen Göttingen — [2]Faculty of chemistry and food chemistry, Technische Universität Dresden, Mommsenstraße 4 01069 Dresden

This work explores the interlayer interaction effects of van-der-Walls heterostructures (HS) formed by graphene and a new class of two-dimensional polymers bonded by covalent bonds (C2DPs). These materials can be synthesized with multiple compositions and topology and therefore offer large tunability of their electronic properties. Via density functional theory calculations, it was possible to predict that coupling of different C2DPs with monolayer graphene should generate new interesting physical phenomena, including band flattening and trivial and non-trivial bandgap opening. The first system studied is the HSs formed by a mechanically exfoliated graphene on top of a C2DP that comprises metal-free porphyrin and perylene units linked by imide bonds. Different techniques are used for the first characterization of the structure: Raman, KPFM, SNOM, and ARPES. These different measurement techniques indicate the existence of interaction effects in the HSs. Electrical measurements on the HSs were also performed and showed that the polymer highly p-dopes the graphene.

TT 29.11 Thu 15:00 P1

Inductive coupling schemes in nano-electromechanics

— •Lukas Niekamp[1,2], Thomas Luschmann[1,2,3], Philip Schmidt[1,2], Frank Deppe[1,2,3], Achim Marx[1], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich

Nano-electromechanics studies the opto-mechanical interaction between microwave frequency resonators and mechanical components in the nanometer regime. Recently, the concept of inductive coupling has been demonstrated, allowing for the modulation of the resonator frequency by the mechanical displacement [1, 2]. This coupling scheme results in higher vacuum opto-mechanical coupling rates compared to previous capacitive coupling schemes. Therefore, devices based on inductive coupling are considered as potential pathway for realizing vacuum strong-coupling. This regime allows to harness the full non-linearity of the optomechanical interaction offering opportunities like the generation of mechanical quantum states. The device presented here consists of a flux-tunable dc-SQUID with mechanically compliant strings integrated into a microwave resonator. The mechanical displacement of the strings modulates the external flux and hence the microwave resonator's frequency. Here, we present recent experiments on the path to strong photon-phonon interaction.

[1] Rodrigues, Bothner, Steele, Nat. Commun. 10, 5359 (2019)
[2] Schmidt et al., Commun. Phys. 3, 233 (2020)

TT 29.12 Thu 15:00 P1

Full counting statistics in periodically driven systems

— •Johann Zöllner, Eric Kleinherbers, and Jürgen König — Theoretische Physik, Universität Duisburg-Essen and CENIDE, Lotharstr. 1, 47048 Duisburg

By calculating the full counting statistics of tunnelling electrons one can obtain information about quantum dot systems. We focus on the factorial cumulants [1] of the full counting statistics in periodically driven systems, which can be calculated using Floquet theory [2]. Higher-order factorial cumulants show signatures that can not be observed in the tunnelling current. To obtain analytical expressions we use the adiabatic approximation for small frequencies or the Magnus expansion for large frequencies. For the adiabatic limit we observe

frequency-doubling in all factorial cumulants.
[1] P. Stegmann et al., Phys. Rev. B 92, 155413 (2015)
[2] E. Potanina et al., Phys. Rev. B 99, 035437 (2019)

TT 29.13 Thu 15:00 P1

Light emission in ΔT-driven mesoscopic conductors — •Matthias Hübler and Wolfgang Belzig — University Konstanz

The scattering approach paves the way for the description of electron transport and current fluctuations in mesoscopic conductors. If fluctuations are coupled to an electromagnetic field, then they are related to the rate at which the field transfers energy to or receives energy from the conductor. The non-symmetrized current-current correlator characterizes the emission and absorption spectrum. Recent interest is concerned with ΔT noise, which is the non-equilibrium noise caused by a temperature difference between the terminals. Here we generalize the notion of ΔT noise to the non-symmetrized current-current correlator at finite frequencies. The spectrum is investigated for energy-independent scattering and for a resonant level as an example of energy-dependent scattering. We find that a temperature difference ΔT leads to a partially negative ΔT noise spectrum. This is a consequence of temperature broadening in combination with a frequency shift of the involved Fermi distributions. In the case of energy-independent scattering, the lowest order is a quadratic $\propto (\Delta T)^2$ correction of the thermal-like noise spectrum. For the resonance, there arises an additional contribution to the ΔT noise spectrum that is $\propto \Delta T$ at the lowest order.

TT 29.14 Thu 15:00 P1

Symmetry-protected Bose-Einstein condensation of interacting hardcore bosons — •Reja Wilke[1], Thomas Köhler[2], Felix Palm[1], and Sebastian Paeckel[1] — [1]Department of Physics, Arnold Sommerfeld Center for Theoretical Physics, University of Munich, Germany — [2]Department of Physics and Astronomy, Uppsala University, Sweden

We introduce a mechanism stabilizing a one-dimensional quantum many-body phase, characterized by a certain wave vector via the protection of an emergent Z2 symmetry. We illustrate this mechanism by constructing the solution of the full quantum many-body problem of hardcore bosons on a wheel geometry, which are known to form a Bose-Einstein condensate. The robustness of the condensate is shown numerically by adding nearest-neighbor interactions to the wheel Hamiltonian. We discuss further applications such as geometrically inducing finite-momentum condensates.

TT 29.15 Thu 15:00 P1

Low temperature photoluminescence investigation of light-induced degradation in boron doped CZ-silicon — •Katharina Peh[1], Kevin Lauer[1,2], Aaron Flötotto[1], Dirk Schulze[1], and Stefan Krischok[1] — [1]TU Ilmenau, Institut für Physik und Institut für Mikro- und Nanotechnologien, Ilmenau, Germany — [2]CiS Forschungsinstitut für Mikrosensorik GmbH, Konrad-Zuse-Str. 14, 99099 Erfurt, Germany

Light-induced degradation (LID) in boron doped Czochralski grown (CZ) silicon is a severe problem for silicon devices such as solar cells or radiation detectors. In this contribution boron doped CZ silicon is investigated by low temperature photoluminescence (LTPL) spectroscopy. As already demonstrated on indium p-doped silicon samples, we suspect an ASi-Sii defect also in boron p-doped silicon samples [1]. To find the defect in connection with an additional LID PL peak which was also published by Vaqueiro-Contreras et al. [2], we carried out numerous measurements on boron-doped samples with the help of LTPL at 10 K.
[1] K. Lauer, C. Möller, D. Schulze, C. Ahrens, AIP Advances 5, 017101 (2015)
[2] M. Vaqueiro-Contreras, V.P. Markevich, J. Coutinho, P. Santos, I.F. Crowe, M.P. Halsall, I. Hawkins, S.B. Lastovskii, L.I. Murin, A.R. Peaker, J. Appl. Phys. 125, 185704 (2019)

TT 29.16 Thu 15:00 P1

Design and construction of low temperature probe for transport measurement — •Reza Firouzmandi, Vilmos Kocsis, Pablo Pedrazzini, Tino Schreiner, Danny Baumann, and Bernd Büchner — Leibniz Institute for Solid State and Materials Research (IFW), 01069 Dresden, Germany

Electrical and thermal transport experiments are fundamental tools of basic research not only because of their potential to reveal new phenomena in condensed matter physics but also to discover novel applications. Here we report on our newly constructed, highly versatile, custom-built, low-temperature transport probes, which will allow us to perform high-precision measurements of electrical and thermal transport properties in a wide series of materials. The probes will allow measurements in the temperature range between 5K and 300K, under applied magnetic fields up to 16T, as well as high electric voltages up to 500V. The probes will be used in the investigation of novel quantum materials and multiferroics.

TT 29.17 Thu 15:00 P1

Lab::Measurement – measurement control with Perl 5 — Mia Schambeck, Erik Fabrizzi, Fabian Weinelt, Simon Reinhardt, and •Andreas K. Hüttel — Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany

`Lab::Measurement` is a collection of object-oriented Perl 5 modules providing control of test and measurement devices. It allows for quickly setting up complex tasks with diverse hardware. Instruments can be connected via GPIB (IEEE 488.2), USB or VXI-11 / raw network sockets on Ethernet. Internally, third-party backends as, e.g., Linux-GPIB, the NI-VISA library, or Zurich Instruments' LabOne API are used, in addition to lightweight drivers for USB and TCP/IP-based protocols. The wide range of supported backends enables cross-platform portability of measurement scripts between Linux and Windows machines. Based on roles within `Moose` that provide communication standards such as SCPI, dedicated instrument driver classes take care of internal details. A high-level sweep layer allows for fast and flexible creation of nested measurement loops, where, e.g., several input variables are varied and data is logged into a customizable folder structure. Features include live plotting or obtaining attested timestamps for measurement data.
`Lab::Measurement` is free software and available at `https://www.labmeasurement.de/` — Reference: S. Reinhardt *et al.*, Comp. Phys. Comm. **234**, 216 (2019)

TT 29.18 Thu 15:00 P1

Theory of difference frequency quantum oscillations — •Valentin Leeb[1] and Johannes Knolle[1,2,3] — [1]Department of Physics TQM, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom

Quantum oscillations (QO) describe the periodic variation of physical observables as a function of inverse magnetic field in metals. The Onsager relation connects the basic QO frequencies with the extremal areas of closed Fermi surface pockets, and the theory of magnetic breakdown explains the observation of sums of QO frequencies at high magnetic fields. Here we develop a quantitative theory of *difference frequency* QOs in metals with multiple Fermi pockets with parabolic or linearly dispersing excitations. We show that a non-linear interband coupling, e.g. in the form of interband impurity scattering, can give rise to otherwise forbidden QO frequencies which can persist to much higher temperatures compared to the basis frequencies. We discuss the experimental implications of our findings, for example, for materials with multifold fermion excitations.

TT 30: Superconductivity: Poster Session

By tradiiton the poster sessions in the Low Temperature Physics ivision are long (3-4 hours). Since temporal overlap with interesting oral sessions cannot be completely avoided, we suggest the poster presenters to leave a note at their posters indicating when they would be available for discussion.

Time: Thursday 15:00–18:00 Location: P1

TT 30.1 Thu 15:00 P1

Optimization of single-crystal growth of Fe(Se,S) — •Maik Golombiewski, Teslin Rose Thomas, N. S. Sangeetha, Andreas Kreyssig, and Anna E. Böhmer — Lehrstuhl für Experimentalphysik IV, Fakultät für Physik und Astronomie, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum

The iron-based superconductor FeSe and its substitution series Fe(Se,S) have been studied intensively for over a decade. Large (mm-sized) homogeneous single crystals are highly desirable for the accurate characterization of this material. An effective technique to grow Fe(Se,S) single crystals is chemical vapor transport with Cl-salts. However, the sulfur substitution makes the growth of large single crystals harder the higher the substitution percentage is.

We examine which parameters have an influence on the size and homogeneity of our Fe(Se,S) single crystals, namely furnace tilt, quartz ampoule dimensions and form, starting material preparation and temperature gradient. The composition of the single crystals is analyzed with a scanning electron microscope and properties are characterized by resistance measurements as well as x-ray diffraction experiments.

We find that we can consistently grow single crystals with masses ranging from 3 mg to more than 10 mg, depending on S-content. Other types of chemical substitution are explored.

TT 30.2 Thu 15:00 P1

Magnetic order in transition-metal doped $CaKFe_4As_4$ and the interplay with superconductivity — •Andreas Kreyssig — Institute for Experimental Physics 4, Ruhr-Universität Bochum, 44801 Bochum, Germany — Ames Laboratory, U.S. DOE, and Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA

$CaKFe_4As_4$ is an iron arsenide superconductor in which partial substitution of Fe by a transition metal shifts the ground state from superconducting to antiferromagnetically ordered. The magnetic structure is a hedgehog spin-vortex crystal arrangement within the Fe planes. This magnetic order is different from the stripe-type spin density wave observed in other iron arsenide superconductor, however, related to the same entangled propagation vectors based on Fermi-surface nesting. In this presentation the determination of the magnetic order will be reviewed and the interplay of the magnetism with superconductivity will be discussed in detail.

This work was supported by the U. S. DOE, BES, DMSE, under Contract DE-AC02-07CH11358. This research used resources at HFIR, a U. S. DOE Office of Science User Facility operated by the Oak Ridge National Laboratory.

TT 30.3 Thu 15:00 P1

Feedback of non-local d_{xy} nematicity on the magnetic anisotropy in FeSe — •Steffen Bötzel and Ilya Eremin — Institut für theoretische Physik III, Ruhr-Universität Bochum, Bochum, Germany

Details of the nematic state in FeSe and its connection to superconductivity are still a matter of debate. We analyze theoretically the magnetic anisotropy in this state by computing the spin and the orbital susceptibilities from a microscopic multiorbital model. In particular, we consider both the xz/yz and the recently proposed non-local xy nematic ordering. The latter is believed to have a significant impact on the bandstructure and to force a Lifshitz transition. Its inclusion could play a crucial role in reproducing the experimentally measured temperature dependence of the magnetic anisotropy. This provides a direct fingerprint of the different nematic scenarios on the magnetic properties of FeSe.

TT 30.4 Thu 15:00 P1

Microscopic theory of the multi-orbital FFLO phase in the iron-based superconductors — •Luka Jibuti and Ilya Eremin — Institute für Theoretische Physik III, Ruhr-Universität Bochum, D-44801 Bochum, Deutschland

We study the superconducting Frude-Ferrel-Larnik-Ovchinnikov (FFLO) phase, a superconducting phase, where Cooper pairs having non-zero center-of-mass momentum $\vec{q}$, in iron-based superconductors. We develop a microscopic theory model considering two Γ-centered hole pockets created by xz and yz orbitals. We write the low energy effective Hamiltonian of the form $\hat{H} = \hat{H}_0 + \hat{H}_{int}$, where the first term includes the kinetic therm, the $\vec{k}$-independent spin orbit coupling and the Zeeman field. We introduce the superconducting pairing between fermions in xz and yz orbitals and we restrict ourselves with the interactions which lead to the inter-band pairing of Cooper pairs. Writing the system Hamiltonian initially in orbital basis allowes us to observe the changes of the orbital weights at the Fermi energy when making the transition from Normal to FFLO phase and pinpoint the direction and value of the center-of-mass momentum $\vec{q}$ that connects particles within the same orbital. From the mean field calculations for magnetic field just above the Pauli limit and for temperatures close to absolute zero, we are able to observe that $\pm\vec{q}$ vectors connect particles within yz and xz orbitals respectively. We also observe that $\vec{q}$ is highly dependent on the magnetic field and temperature, and the increase of the SOC constant destroys the FFLO phase.

TT 30.5 Thu 15:00 P1

In search of the superconducting symmetries of $CeRh_2As_2$ — •Fabian Jakubczyk[1,2], Julia M. Link[1,2], and Carsten Timm[1,2] — [1]Institute of Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany

Multiphase unconventional superconductivity is a rare phenomenon, which has recently been discovered in the heavy-fermion compound $CeRh_2As_2$. Here, the transition between two distinct superconducting phases occurs as a function of magnetic field applied along the c axis.At $\mu_0 H^* \approx 4\,\mathrm{T}$ the superconductor changes from a low-field to a high-field state with a large critical field of $\mu_0 H_{c2} = 14\,\mathrm{T}$. However, for in-plane fields only the low-field phase appears, with $\mu_0 H_{c2} = 2\,\mathrm{T}$. Furthermore, at $T_0 \approx 0.4\,\mathrm{K}$ a transition to a suggested quadrupole-density-wave state was reported, whilst the low-field superconducting state is reached at $T_c = 0.26\,\mathrm{K}$. Intriguingly, this quadrupole-density-wave state seems to be suppressed by a c axis field of about H^*, such that the low-field phase lies within it, whereas the high-field state does not. It seems reasonable to assume that the change of superconducting properties might be triggered by the disappearing density-wave state. In order to analyze this and other possible scenarios, we first conduct a symmetry analysis of the locally noncentrosymmetric $CeRh_2As_2$. Moreover, we construct a Landau-type energy functional including the superconducting and density-wave order parameters, as well as the applied magnetic field. From this we can give a statement about the potential symmetries of the superconducting phases.

TT 30.6 Thu 15:00 P1

Ising superconductors: the signatures of triplet pairings in the density of states and vanishing of the "mirage" gap — •Sourabh Patil[1], Gaomin Tang[2], and Wolfgang Belzig[1] — [1]Universität Konstanz, Konstanz, Germany — [2]University of Basel, Basel, Switzerland

The conventional 2D superconductors are governed by the critical in-plane magnetic field above which the superconductivity is destroyed. Monolayer transition-metal dichalcogenides lack inversion symmetry and along with a strong spin-orbit coupling, lead to valley-dependent Zeeman-like spin splitting. This is the Ising spin-orbit coupling (ISOC) which then lifts the degeneracy of the two valleys and enhances the in-plane critical magnetic field. The finite energy pairings are thus obtained in such systems. The main superconducting gap-like feature shifted to finite energy is observed and termed a mirage gap.

The triplet pairings are introduced by the applied field. The equal-spin triplet pairing is always coupled to the singlet pairing, reflected in the self-consistent equations. Importantly, as the applied field is increased, we observe that the mirage gap closes (vanishes) and reopens. We obtain a phase diagram for such vanishing of the mirage gap in the 3D parameter space of the applied field, temperature, and the critical triplet temperature, for a fixed ISOC. The role of topology in such a mirage gap closing and any observable physical effects on the superconductivity would be our topic of study.

[1] G. Tang et. al., Phys. Rev. Lett. 126, 237001 (2021)
[2] M. Kuzmanović et. al., arXiv:2104.00328 (2021)

TT 30.7 Thu 15:00 P1

Time-reversal symmetry breaking in the superconducting state of ScS — •Arushi Arushi[1,2], Roshan Kumar Kushwaha[1], Deepak Singh[3], Adrian Hillier[3], Mathias S Scheurer[4], and Ravi Prakash Singh[1] — [1]Indian Institute of Science Education and Research Bhopal, Bhopal, India — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [3]ISIS Facility, STFC Rutherford Appleton Laboratory, Didcot, United Kingdom — [4]Institute for Theoretical Physics, University of Innsbruck, Innsbruck, Austria

The study of unconventional superconductors, which go beyond the BCS theory, is a crucial pillar of modern condensed-matter research and it is driven by the potential of these superconductors for applications and by fundamental scientific question, such as understanding their pairing mechanism. For the latter, time reversal-symmetry-breaking superconductivity might be particularly interesting since it is rare in nature and the underlying pairing mechanism must involve more than the conventional electron-phonon coupling. In this regard, we studied the superconducting state of ScS(rocksalt structure) using macroscopic and microscopic measurements such as muon spin rotation/relaxation(μSR). All the performed measurements confirmed the bulk superconductivity at 5.1(1) K. Specific heat together with transverse-field μSR measurements indicate a full gap, while our zero-field μSR study reveals the presence of spontaneous static or quasistatic magnetic fields emerging when entering the superconducting state. We discuss various theoretical possibilities of pairing mechanisms, hint towards an unconventional superconducting state in ScS.

TT 30.8 Thu 15:00 P1

Topological phase transition away from the Fermi surface in multiband superconductors — •Masoud Bahari[1], Song-Bo Zhang[2], Chang-An Li[1], Carsten Timm[3], and Björn Trauzettel[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany — [2]Department of Physics, University of Zurich, Winterthurerstrasse 190, 8057, Zurich, Switzerland — [3]Institute of Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany

We demonstrate theoretically that odd-parity multiband superconductors with inversion symmetry host dispersive topological surface states induced solely by interband pairing away from the Fermi surface. The normal state requires to have at least a pair of energy bands with different effective masses. In this regard, spin-orbit coupling is a key ingredient. The topological phase transition occurs between electrons with different quantum numbers at finite excitation energies. Such phase transition happens at direction where the inter- and intraband electron pairings are finite and vanishing at the same time. To capture the underlying physics, we develop a generic theory in the interband representation of Bogoliubov-de Gennes Hamiltonian. We apply our theory to j=3/2 systems and we discuss the pairing channels hosting such surface states.

TT 30.9 Thu 15:00 P1

Majorana flat bands at structured surfaces of nodal noncentrosymmetric superconductors — •Clara Johanna Lapp and Carsten Timm — Institute of Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany

Surfaces of nodal noncentrosymmetric superconductors can host flat bands of Majorana modes, which provide a promising platform for quantum computation if one can find methods for manipulating localized Majorana wave packets. We study the fate of such flat bands when part of the surface is subjected to an exchange field induced by a ferromagnetic insulator. Exact diagonalization is used to find the eigenstates and eigenenergies of the Bogoliubov-de Gennes Hamiltonian of a model system, for which an exchange field is applied along a strip on the surface of a slab. Moreover, we discuss a setup with a small exchange field applied to the previously field-free strip with the goal of introducing a linear dispersion. By switching this dispersion on and off, a wave packet could be moved in a certain direction. We find that in our model system, a linear dispersion can indeed be achieved. The qualitative features of this dispersion can be predicted from the momentum-dependent spin polarization of the field-free surface.

TT 30.10 Thu 15:00 P1

Piezoelectric control of the electrical field-effect in superconductors — •Leon Ruf, Sara Khorshidian, Sohaila Noby, Jennifer Koch, Elke Scheer, and Angelo Di Bernardo — Department of Physics, University of Konstanz, Konstanz, Germany

Superconducting (sc) transistors are promising building blocks for future superconductors by virtue of their low energy consumption. For real applications this requires devices with Complementary metal-oxide-semiconductor (CMOS) compatibility, high switching speed and high scalability. Some realizations of superconductor/semiconductor hybrid systems, such as Nanocryotrons (nTrons) [1] or thermal driven sc-nanowires (hTron) [2] have already been put forward. An alternative promising architecture are gate-controlled sc devices. Reversible switching via gate-controlled sc-transistors (EF-Trons) has been independently seen for various BCS superconductors, such as Ti [3] and V [4]. Still the physical effect of the EF-Trons is not fully understood and is under debate [5]. By coupling epitaxial piezo-/ferroelectrics to the EF-Trons, we investigate the role of strain and amplification of the electric field through these materials on the switching behavior. We present first results of the growth of epitaxial piezo-/ferroelectrics and characterization of EF-Trons coupled with piezo-/ferroelectrics.

[1] A. N. McCaughan et al., Nano Lett. 14, 5748 (2014)
[2] A. N. McCaughan et al., Nat. Electron. 2, 451 (2019)
[3] G. De Simoni et al., Nat. Nanotechnol. 13, 802 (2018)
[4] F. Paolucci et al., AVS Quantum Sci. 1, 016501 (2019)
[5] I. Golokolenov et al., Nat. Commun. 12, 2747 (2021)

TT 30.11 Thu 15:00 P1

Gate effect on superconducting metal and metal oxide-based nanodevices — •Sohaila Mohammed, Sara Khorshidian, Angelo di Bernardo, and Elke Scheer — Physics Department, University of Konstanz

Quantum devices based on superconducting materials provide various technological applications, such as e.g. current limiters, electronic filters, routers, digital receivers, and photon detectors. The recent discovery of the reversible modulation of the superconducting critical current (I_c) in nanowires and Dayem bridges under the application of a gate voltage has raised a lot of interest for the possible application of this phenomenon towards the realization of superconducting logic devices. The threshold voltages necessary for the full suppression of I_c, however, remain high and correspond to an electrostatic field of $\sim$ 4 MV/cm. Also, the physical origin of the effect remains controversial. To better understand the mechanism responsible for the suppression of I_c and to determine the physical parameters that can be useful to reduce the high electrostatic fields currently needed for the switching, we have performed a systematic investigation of gate-controlled superconducting devices made of different metal and metal-oxide superconductor materials. We report on our findings and discuss the physical parameters relevant to assess the performance of gate-controlled superconducting devices including their maximum operational temperature, kinetic inductance, leakage currents and switching voltages.

TT 30.12 Thu 15:00 P1

Gate-voltage mediated supercurrent suppression in a superconducting nano-bridge — •Subrata Chakraborty, Danilo Nikolic, and Wolfgang Belzig — Fachbereich Physik, Universität Konstanz, D-78467 Konstanz, Germany

Voltage-gated supercurrent suppression in a superconducting nano-bridge is a hot topic for research in present days. Recent experiments on this effect demonstrate a sudden supercurrent suppression in the bridge with high gate-voltage [1-6]. The microscopic understanding of this is not settled till now. According to the experimental researches, there are three distinct tentative mechanisms, which could be responsible for this event. These mechanisms suggest that at high gate voltage there could be either a direct surface-pair breaking-induced phase transition, superconductivity suppression with induced nonequilibrium phonon distribution due to Joule heating in the gate or supercurrent suppression due to nonequilibrium electronic quasiparticles via a direct small leakage current. In our work, we theoretically investigate the role of gate-voltage induced surface-pair breaking on the supercurrent suppression of superconducting nano-bridge. We speculate this work would present some generic theoretical predictions of this effect allowing to further test it experimentally.

[1] M. Rocci *et al.* *ACS Nano*, **14**, 12621 (2020)
[2] I. Golokolenov *et al*, *Nat. Commun.*, **12**, 2747 (2021)
[3] L.D. Alegria *et al.*, *Nat. Nanotechnol.*, **16**, 404 (2021)

TT 30.13 Thu 15:00 P1

Tunable superconducting single electron transistors: from weak to strong-coupling regime — •Oliver Irtenkauf[1], Laura Sobral-Rey[1], David Ohnmacht[1], Wolfgang Belzig[1], Jens Siewert[2], and Elke Scheer[1] — [1]Univ. Konstanz — [2]Univ. del Pais Basque, Bilbao, Spain

An island coupled to two leads and a gate forms a single electron transistor (SET) that shows Coulomb blockade (CB). All-superconducting SETs have shown to enable a multitude of possible charge transport processes, not all of them are well understood [1], in particular in the strong-coupling regime [2]. The conceptually simpler SSN-SET reduces the number of possible processes. We study a device consisting of a S island coupled to a N lead via an oxide tunnel barrier, and to a S lead with a mechanically controlled break junction (MCBJ). Via the MCBJ, different coupling regimes can be studied from a tunnel contact to a point contact [2]. For weak coupling, our experimental findings in the N state can be understood in terms of the Orthodox Theory of CB [3,4]. For stronger coupling, we observe Andreev and Josephson transport as well as, in the N state, a renormalization of the charging energy [5,6]. We describe our experimental results in the S state with simulations based on a generalized master equation approach [7].

[1] J.M. Hergenrother et al., PRL 72, 1742 (1994)
[2] T. Lorenz et al., JLTP 191, 301 (2017)
[3] D. V. Averin, K. K. Likharev, JLTP 62, 345 (1986)
[4] H. Grabert, M. H. Devoret, NATO Sci. Ser. B, 294 (1992)
[5] P. Joyez et al., PRL 79, 1349 (1997)
[6] S. Jezouin et al., Nature 536, 58 (2016)
[7] J. Siewert, G. Schön, PRB 54, 7421 (1996)

TT 30.14 Thu 15:00 P1

Interplay between charging effects and superconducting transport in a tunable SET — •David Christian Ohnmacht[1], Laura Sobral Rey[1], Jens Siewert[2], Wolfgang Belzig[1], and Elke Scheer[1] — [1]Universität Konstanz, Konstanz, Deutschland — [2]University of the Basque Country, Bilbao, Spain

All-superconducting single electron transistors (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, the conceptually simpler (SSN)-SET, which has never been investigated experimentally before is considered [2]. Electron tunneling, Cooper pair tunneling and (multiple) Andreev reflection ((M)AR) are possible in the S-S mechanically controlled break junction (MCBJ) which can be adjusted to cover all coupling regimes: from a tunnel contact to a point contact with a small number of highly transmissive transport channels. The experimental data is compared to theoretical results obtained by using a master equation approach, including the rates of different transport mechanisms [3]. In order to account for MAR, we include the rates for the individual processes which are obtained from the theory of full counting statistics into the master equation framework [4]. The rates for MAR are computed using transmission probabilities according to the experimental data taking into account the presence of multiple transport channels. The limits of this master equation approach for a SSN-SET with a MCBJ are discussed in detail. Finally, it is shown that the charging energy decreases as the coupling of the MCBJ increases.

TT 30.15 Thu 15:00 P1

Preparation of Nb/MnSi heterostructures — •Julius Grefe[1], Rodrigo de Vasconcellos Lourenço[2], Markus Etzkorn[2,3], Stefan Süllow[1], and Dirk Menzel[1,3] — [1]IPKM, TU Braunschweig, Germany — [2]IAP, TU Braunschweig, Germany — [3]LENA, TU Braunschweig, Germany

Motivated from theoretical predictions [1], the preparation of Nb/MnSi heterostructures, which are candidates for the usage as superconducting spin valves, is introduced. The substrates are obtained by cutting oriented Triarc-Czochralski grown MnSi single crystals into thin disc-shaped wafers. The surfaces of these substrates are prepared by various polishing steps, wet chemical etching, Ar sputtering and thermal annealing. After these processes the surfaces have been investigated by AFM and TEM and show surface roughnesses in the order of 1 nm. In order to investigate proximity effects between the chiral magnet MnSi and a superconductor we have deposited onto the substrates thin Nb films using molecular beam epitaxy. These heterostructures have been investigated in terms of magnetoresistivity measurements.

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

TT 30.16 Thu 15:00 P1

Orientation-dependent magnetoresistance of Nb/MnSi heterostructures — •Philip Schröder[1], Julius Grefe[1], Stefan Süllow[1], and Dirk Menzel[1,2] — [1]Institut für Physik der Kondensierten Materie, TU Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, TU Braunschweig, Germany

During high-resolution four probe (magneto-)resistivity measurements the reliability of the data strongly depends on the contacts' characteristics. If a vector magnet is not available the change of the sample orientation with respect to the field always requires demounting, reorientation and recontacting of the sample. We have measured the resistivity of a superconducting Nb thin film deposited on a helimagnetic MnSi substrate as function of the angle between the surface and the external magnetic field. In order to maintain the same four-probe configuration without recontacting an experimental setup has been developed allowing 720° sample rotation in a homogeneous field up to 1.1 T. The setup is used to accurately investigate the shift due to the proximity effect of the critical temperature T_c of the Nb film in contact to a magnetic system exhibiting a non-collinear spin structure. We show that the spin-helix orientation of the MnSi substrate is able to tune the T_c of Nb so that this heterostructure can be used as a two-component superconducting spin valve.

TT 30.17 Thu 15:00 P1

Decoupling of $NbSe_2$ monolayers in tailored SnSe-based multilayers — •O. Chiatti[1], K. Mihov[1], T. Griffin[1], C. Grosse[1], M. B. Alemayehu[2], K. Hite[2], D. Hamann[2], A. Mogilatenko[3], 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. — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany

Van-der-Waals superlattices with two-dimensional (2D) superconducting layers of a transition-metal dichalchogenide (TMD) embedded between other materials have received a lot of attention [1]. Here, we examine the coupling between the $NbSe_2$ monolayers in $[(SnSe)_{1+\delta}]_m[NbSe_2]$ ferecrystals [2]. m is an adjustable parameter to control the spacing between $NbSe_2$ layers and tune the inter-layer coupling, with a crossover from 3D to 2D superconductivity. The electric transport shows three regions: I. for $m = 1 - 4$ the films resemble "good" metals and 3D anisotropic superconductors, with inter-layer coupling enhanced by proximity effect in the SnSe layers and charge transfer from $NbSe_2$ to SnSe; II. for $m = 5 - 9$ the films are "dirty" metals and 3D anisotropic superconductors, with inter-layer coupling reduced by disorder and smaller charge transfer; III. for $m > 9$ they are "bad" insulators and a stack of disordered quasi-2D superconductors, with Josephson coupling between $NbSe_2$ monolayers.

[1] A. Devarakonda *et al.*, Science **370**, 231 (2020)
[2] M. Trahms *et al.*, Supercond. Sci. Technol. **31**, 065006 (2018)

TT 30.18 Thu 15:00 P1

Spin-orbit effects in the vortex inductance of Al/InAs heterostructures — •Jaydean Schmidt, Lorenz Fuchs, Denis Kochan, Maximillian Ufer, Simon Reinhardt, Michael Prager, Matthias Kronseder, Dominique Bougeard, Nicola Paradiso, and Christoph Strunk — University of Regensburg (Germany)

In this work, we demonstrate the interplay of spin-orbit interaction and in-plane magnetic field in synthetic Rashba superconductors. We investigate the vortex inductance of epitaxially grown Al/InAs heterostructures containing an high-mobility surface-near InAs quantum well covered with a epitaxial layer of aluminum. An AC-current drives vortex oscillations around pinning centers which can be probed via inductance. The vortex inductance was found to be orders of magnitude larger than the kinetic inductance. When applying an in-plane field, the vortex inductance drops in particular for $B_{\parallel} \perp I_{AC}$ signaling an increase of the pinning force. With respect to the angle between magnetic field and ac-current, a prominent two-fold anisotropy is observed. The unusual behavior of the vortex inductance signals a deformation of the vortex cores and can be theoretically explained by introducing an additional term in the Ginzburg-Landau free energy of a superconductor, resulting from the Rashba spin-orbit interaction [1].

[1]L. Fuchs et al., arXiv: 2201.02512

TT 30.19 Thu 15:00 P1

Generalising Beenakker equation to take into account evanescent modes — •Daniel Kruti and Roman-Pascal Riwar — Institute for Theoretical Nanoelectronics (PGI-2), Jülich Research Centre and Institute for Theoretical Physics, University of Cologne

Superconductor–normal-metal–superconductor Josephson junctions have been examined extensively in past years. In particular, the case where the normal region is modelled by an ideal normal conductor with an intermittent scattering region can be well described by the celebrated Beenakker equation. Strictly speaking however, this equation is applicable only in the asymptotic plain wave limit, neglecting evanescent modes. However, the situation is changing by recent experimental advances. First, conductor regions are now fabricated with significantly decreased impurity scattering, leading to situations where scattering is dominated by the junction geometry. Second, miniaturisation is advancing such that evanescent modes should no longer be neglected. While this regime has already been captured by numerical methods, we here strive for an explicit analytical treatment, and generalise the Beenakker equation to short junctions with geometric scattering.

TT 30.20 Thu 15:00 P1

Controlling the Critical Current in Ferromagnetic Josephson-Junctions by Magnetization and Microwave Irradiation — •Lukas Kammermeier, Andreas Bloch, Oliver Irtenkauf, and Elke Scheer — Universität Konstanz, Konstanz, Germany

A key building block in superconducting spintronics is a controllable superconducting device that accomodates long-ranged triplet currents [1]. It has been suggested to create long range triplets with the help of ferromagnetic resonance in superconductor-ferromagnet-superconductor (SFS) structures made of conventional s-wave superconductors [2]. Here we explore this possibility by studying the electronic transport in SFS junctions in different geometries and realizations of the F spacer, subject to microwave irradiation, with spin injection and as function of the magnetization state of the ferromagnet. We show that we can manipulate the critical current of overdamped S-S/F-S proximity junctions by several percent by flipping a single domain in the ferromagnet. First results on spin injection will be presented.

[1] J. Linder, W. A. Robinson, Nat. Phys. 11, 307 (2015)
2] S. Takahashi, S. Hikino, M. Mori, J. Martinek, S. Meakawa, Phys. Rev. Lett. 99, 057003 (2007)

TT 30.21 Thu 15:00 P1

A Ballistic Graphene Cooper Pair Splitter — Preeti Pandey[1], Romain Danneau[2], and •Detlef Beckmann[2] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology, D-76021 Karlsruhe, Germany — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, D-76021 Karlsruhe, Germany

We report an experimental study of a Cooper pair splitter based on ballistic graphene multiterminal junctions. In a two transverse junction geometry, namely the superconductor-graphene-superconductor and the normal metal-graphene-normal metal, we observe clear signatures of Cooper pair splitting in the local as well as nonlocal electronic transport measurements. Our experimental data can be very well described by our beam splitter model. These results open up possibilities to design new entangled state detection experiments using ballistic Cooper pair splitters.

[1] Phys. Rev. Lett. 126, 147701 (2021)

TT 30.22 Thu 15:00 P1

Coupling of supercurrent and quasiparticle excitations in superconductor nanostructures — •Paul Maier and Detlef Beckmann — Institut für Quantenmaterialien und Technologien, Karlsruher Institut für Technologie

We report on the experimental observation of coupling between nonequilibrium modes of the quasiparticle excitations in thin superconducting films in the presence of supercurrent and high parallel magnetic fields. The coupling is due to a difference in the number of available quasiparticle states, depending on their relative propagation direction to the supercurrent. Recently the occurrence of a spin-energy (spin-antisymmetric charge imbalance) current in the presence of energy imbalance was predicted [1]. Here the resulting spin-energy imbalance for a spatial gradient in the energy imbalance was probed in nonlocal conductance measurements with spectral resolution. The measurements show excellent agreement with numerical models and provide proof of the coupling of energy and spin-energy modes.

[1] F.Aikebaier et al., Phys. Rev. B 98, 024516 (2018)

TT 30.23 Thu 15:00 P1

Bloch oscillation effects in ultrasmall Josephson junctions embedded in high-inductance environment — •Fabian Kaap and Sergey Lotkhov — Physikalisch-Technische Bundesanstalt, Bundesallee 100 38116, Deutschland Braunschweig

The adiabatic transport of Cooper pairs, also known as Bloch oscillations(BO), can be of high interest in future applications for metrology, due to the fundamental current-to-frequency relation, $I_B = 2e \times f_B$. In order for the BO in ultrasmall Josephson junctions to be observed, one has to suppress the quantum fluctuations of charge by means of embedding the junctions into a high impedance environment.

For this purpose, we elaborated a dedicated inductively-resistive planar biasing circuit, which includes high-kinetic-inductance meanders made from granulated aluminium and high-ohmic microstrips of partially oxidized titanium. Using this approach, we were able to measure the characteristic back-bending in an IV-curve of a dc-biased SQUID with Josephson junction of sub-100nm-sizes. By varying the ratio of the Josephson energy E_J and the charging energy E_C, using an external magnetic field, we were able to manipulate the shape of the IV-curves back-bending, which can be explained by a modification of the lowest Bloch energy band of Cooper pairs. With this biasing technique the way is paved to circumvent the microwave coupling issues hindering the realization of dual Shapiro step experiments.

TT 30.24 Thu 15:00 P1

Superconductor-insulator transition in ultra-thin granular aluminum films — •Thomas Huber[1], Aviv Moshe[2], Guy Deutscher[2], and Christoph Strunk[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, Regensburg, Germany — [2]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel

The relation between homogenously disordered and granular superconductors is so far not clearly understood. In particular, the existence of highly insulating states in grAl has yet not been demonstrated. Here we investigate ultra-thin grAl films in the truely 2D limit and find a superconducting transition for sample S with $R_\square(4K) \approx 3k\Omega$ and insulating behavior for sample I with $R_\square(4K) \approx 7.75k\Omega$ (d-SIT). By increasing the perpendicular magnetic field we drive both samples (deeper) into the insulating regime (B-SIT), where we find activated behavior in a temperature range $T^*(B) < T < \approx 800mK$. For $T < T^*$ and $B < \approx 1T$, the R(T) curves saturate, indicating an intermediate anomalous metallic state [1] on both sides of the SIT [2]. The resistance $R_\square$, the activation energy E_A and the threshold voltage V_T depend on magnetic field and show strong similarities to the behavior of both regular Josephson junction arrays [3] and homogenously disordered films [4].

[1] A. Kapitulnik *et al.*, Rev. Mod. Phys. **91**, 011002 (2019)
[2] X. Zhang *et al.*, arXiv:2201.08801 [cond-mat.supr-con] (21.01.2021)
[3] P. Delsing *et al.*, AIP Conference Proceedings **427**, 313 (1998)
[4] T.I. Baturina *et al.*, Phys. Rev. Lett. **99**, 257003 (2007)

TT 31: Superconducting Electronics and Cryogenics: Poster Session

In case the presenters cannot be present at their posters for the full duration of the poster session, they are kindly requested to leave a note at their poster indicating when they will be available for discussion.

Time: Thursday 15:00–18:00 Location: P1

TT 31.1 Thu 15:00 P1

Modular architecture for circuit quantum electrodynamics — •Soeren Ihssen[1], Simon Geisert[1], Martin Spiecker[2], Patrick Paluch[2], Elie de Seze[1,3], Wolfgang Wernsdorfer[1,2], Patrick Winkel[4], and Ioan Pop[1,2] — [1]Institute for Quantum Materials and Technologies, KIT, Germany — [2]Physikalisches Institut, KIT, Germany — [3]ENS Paris-Saclay, France — [4]Yale University, USA

Superconducting quantum circuits play a pioneering role in finding a scalable architecture for the realization of a coherent quantum processor. In this context, keeping the integrity, individual addressability and controllability of each circuit component while increasing the complexity of the whole system is paramount to building a functional device. Fulfilling these key requirements becomes more difficult when increasing the connectivity in the circuit since parasitic cross-talk and the number of decay channels increase at the same time. Therefore, the coupling, readout and control mechanisms of every architecture need to be understood in great detail. Here, we investigate a flip-chip architecture in which we implement the readout and flux control of generalized flux qubits. With our approach, circuits serving different tasks within the system can be prepared individually and exchanged in case they do not fulfil the requirements. In our first realization, a bandpass Purcell filter for readout and an on-chip flux bias line are fabricated and tested regarding their microwave properties. The developed circuit enables a suitable easy-access framework for future experiments on qubit-qubit coupling in a well-controlled microwave environment.

TT 31.2 Thu 15:00 P1

Flip chip implementation for generalized flux qubits — •Simon Geisert[1], Sören Ihssen[1], Martin Spiecker[1,2], Patrick Paluch[1,2], Dennis Rieger[2], Simon Günzler[2], Elie De Seze[3], Wolfgang Wernsdorfer[1,2], Patrick Winkel[1,4], and Ioan Pop[1,2] — [1]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology (KIT), Germany — [2]Physikalisches Institut, KIT, Germany — [3]ENS Paris-Saclay, France — [4]Yale University, USA

Superconducting flux qubits are a versatile and promising platform to implement coherent and tunable qubits with high anharmonicity. In this work, we investigate a generalized flux qubit consisting of a single Josephson junction (JJ) shunted by a capacitance and a granular aluminum inductor. When biased at the flux degeneracy point, the potential landscape can be widely engineered by exploring the parameter space of the flux qubit, which includes the loop inductance, the Josephson energy of the JJ and the total capacitance across the latter. We demonstrate a high engineerability of the qubit frequency, yielding flux qubits in the range of 150 MHz to 7.6 GHz. Dispersive readout of the qubit state is performed via an embedded harmonic mode that is inductively coupled through an asymmetry of the qubit loop. The readout mode is capacitively coupled to a control chip, which is used to excite, read out and flux bias the qubit. This flip chip approach allows very well isolated qubits to be tested in a modular architecture and enables coupling to two distinct coupler chips, effectively creating a unit cell that can be scaled up to an array of coupled qubits.

TT 31.3 Thu 15:00 P1

Simultaneous quantum jumps on multiple Fluxonium qubits — •Nicolas Gosling, Martin Spiecker, Patrick Paluch, Simon Geisert, and Ioan M Pop — Karlsruhe Institut of Technology

Superconducting quantum circuits have become one of the front runners for the implementation of scalable quantum processors. Hereby, the ability to design and implement multiple artificial atoms and their couplings has become an important task for many researchers. Therefore it is imperative to understand how events on one qubit influence other qubits on the same chip. Here, we take simultaneous quantum jump traces of multiple Fluxonium qubits on the same chip using a frequency multiplexed readout scheme through dispersive measurement. The simultaneity is ensured by the frequency multiplexing, enabling both signals to use the same input and output lines. The resulting quantum jump traces are then analysed for simultaneous events in respect to the stochastically expected coherences for perfectly uncoupled quantum systems.

TT 31.4 Thu 15:00 P1

Characterization of Josephson photonics devices as microwave sources for a quantum radar — •Lukas Danner[1,2], Ciprian Padurariu[2], Joachim Ankerhold[2], and Björn Kubala[1,2] — [1]Institute for Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [2]ICQ and IQST, Ulm University, Ulm, Germany

In Josephson photonics devices, microwave radiation is created by inelastic Cooper pair tunneling across a dc-biased Josephson junction connected in-series with a microwave resonator [1]. Various resonances are accessed by tuning the dc-voltage, where, e.g., each tunneling Cooper pair creates one, two or three photonic excitations in the resonator. If excitations are created in two different resonators, the device could be used in a quantum radar which exploits the quantum correlations of the photons [2]. The source can be characterized by the steady-state Wigner density of the cavities, showing e.g. two-mode squeezing or other phase-space symmetries for multi-photon creation. Wigner-state tomography is expensive and in Josephson photonics devices especially challenging due to lacking phase stability. Therefore, we propose an alternative approximative characterization scheme which requires measuring only a few expectation values. A different way of dealing with the instability of the phase-space angle by a locking mechanism [3] is discussed in the contribution of F. Höhe.

[1] M. Hofheinz et al., Phys. Rev. Lett. 106, 217005 (2011)
[2] A. Peugeot et al., Phys. Rev. X 11, 031008 (2021)
[3] L. Danner et al., Phys. Rev. B 104, 054517 (2021)

TT 31.5 Thu 15:00 P1

Reflection-type superconducting microwave resonators for spin-based quantum memories — •Julian Franz[1,2], Patricia Oehrl[1,2], Manuel Müller[1,2], Thomas Luschmann[1,2,3], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [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 Technologies (MCQST), Munich, Germany

Solid-state spin ensembles are considered as excellent candidates for quantum memory applications due to their long coherence times and frequency compatibility with superconducting quantum circuits. The realization of such quantum memory requires the conversion of quantum microwave signals to excitations in the spin ensemble, their storage, and retrieval. This requires the detailed understanding and design optimization of the employed microwave circuit. The excitation transfer is typically measured by using a hanger type resonator. However, in a reflection-type geometry, all of the signal power is available for measurement, which gives nominally a factor of 2 improvement of the signal-to-noise ratio relative to the hanger configuration [1]. Here, we discuss the design concepts for superconducting microwave circuits with emphasis on tuning the coupling rates to the microwave circuit environment and the spin ensemble. In addition, we present experimental data using thin film NbTiN and Nb reflection-type resonators and characterize their performance at mK temperatures.

[1] H. Wang *et al.*, Quantum Sci. Technol., **6** (3), 035015 (2021)

TT 31.6 Thu 15:00 P1

MOCCA: A 4k-pixel molecule camera for the position and energy resolved detection of neutral molecule fragments — •Daniel Kreuzberger[1], Christian Enss[1], Andreas Fleischmann[1], Lisa Gamer[2], Loredana Gastaldo[1], Christopher Jakob[2], Ansgar Lowack[1], Oldřich Novotny[2], Andreas Reifenberger[1], Dennis Schulz[1], and Andreas Wolf[2] — [1]Heidelberg University — [2]Max Planck Institute for Nuclear Physics, Heidelberg

The MOCCA detector is a 4k-pixel high-resolution molecule camera based on metallic magnetic calorimeters and read out with SQUIDs that is able to detect neutral molecule fragments with keV kinetic energies. It will be deployed at the Cryogenic Storage Ring CSR at the

Max Planck Institute for Nuclear Physics in Heidelberg, a storage ring built to prepare and store molecular ions in their rotational and vibrational ground states, enabling studies on electron-ion interactions. To reconstruct the reaction kinematics, MOCCA measures the energy and position of incident particles on the detector, even with multiple particles hitting the detector simultaneously.

We present a new read-out scheme which uses only 32 SQUID channels for the 4096 pixels of the detector as well as some new fabrication details including a new thermalization system and first experimental results.

TT 31.7 Thu 15:00 P1

From ECHo-1k to ECHo-100k: Optimisation of the High-Resolution Metallic Magnetic Calorimeters with Embedded ^{163}Ho — •Markus Griedel[1], Arnulf Barth[1], Sebastian Berndt[2,3], Lorenzo Calza[1], Holger Dorrer[3], Christoph Düllmann[3,4,5], Christian Enss[1], Andreas Fleischmann[1], Daniel Hengstler[1], Tom Kieck[3,4,5], Nina Kneip[2], Neven Kovac[1], Federica Mantegazzini[1], Andreas Reifenberger[1], Alexander Karol Slawik[1], Klaus Wendt[2], and Loredana Gastaldo[1] — [1]Kirchhoff-Institute for Physics, Heidelberg University — [2]Institute of Physics, Johannes Gutenberg University Mainz — [3]Department of Chemistry - TRIGA Site, Johannes Gutenberg University Mainz — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH — [5]Helmholtz Institute Mainz

The ECHo collaboration aims to determine $m(\nu_e)$ by analysing the ^{163}Ho electron capture spectrum. Arrays of tens to hundreds of Metallic Magnetic Calorimeters (MMCs) implanted with ^{163}Ho have been chosen because of their excellent energy resolution in the range of a few eV, their fast response time below 1 μs and their good linearity. The MMC array enclosing ^{163}Ho fabricated for the ECHo-1k phase has been fully characterised in terms of detector response, energy resolution and ^{163}Ho activity. Based on these results a new 64-pixel-array design has been conceived for ECHo-100k, featuring an optimised single pixel geometry and allowing for a ^{163}Ho activity of 10 Bq per pixel. First wafers, each with 40 ECHo-100k chips, have been fabricated and characterised. The obtained results show that the ECHo-100k array achieved the expected performance, especially an average energy resolution of 3.5 eV, fulfilling the requirements for the ECHo-100k phase.

TT 31.8 Thu 15:00 P1

Towards large-area 256-pixel MMC arrays with multiplexed read-out based on flux-ramp modulated dc-SQUIDs — •A. Abeln, S. Allgeier, L. Eisenmann, D. Hengstler, N. Kahne, F. Krämer, D. Mazibrada, L. Münch, A. Stoll, A. Fleischmann, and C. Enss — Kirchhoff-institute for Physics, Heidelberg University

Metallic Magnetic Calorimeters (MMCs) are energy-dispersive cryogenic particle detectors. Operated at about 20 mK, they provide very good energy resolution of down to 1.6 eV at 6 keV, high quantum efficiency as well as linearity over a large energy range. In many precision based experiments on high resolution X-ray spectroscopy the photon flux is small, thus a large active detection area is desirable. Therefore, arrays with a large number of MMC pixels are beneficial. For a cost-effective read-out of a growing number of detector channels we develop different multiplexing techniques.

In this contribution we present the design of a novel 16 × 16 pixel MMC array. Each pixel provides an active detection area of $250\,\mu\text{m}\times 250\,\mu\text{m}$ yielding a total active detection area of about 4 mm × 4 mm. With a thickness of 5 μm the absorbers made of gold ensure a quantum efficiency of at least 50 % for energies up to 20 keV. The designed energy resolution according to numerical simulations is $\Delta E_{FWHM} = 1.4$ eV at an operation temperature of 20 mK. We also present the current status of flux-ramp multiplexing that allows to reduce the number of read-out channels by at least a factor of four compared to a conventional read-out.

TT 31.9 Thu 15:00 P1

PrimA-LTD: Magnetic microcalorimeters for primary activity standardization — •Michael Müller, Ria-Helen Zühlke, Peter Kähler, and Sebastian Kempf — Institute of Micro- and Nanoelectronic Systems, Karlsruhe Institute of Technology, Karlsruhe

Magnetic microcalorimeters (MMC) are cryogenic, energy-dispersive single-particle detectors that consist of a paramagnetic temperature sensor which is in strong thermal contact with a particle absorber. The sensor is magnetized by a magnetic field generated by a persistent current in an underlying superconducting pickup coil. The resulting change of sensor magnetization upon an energy input into the detector is read out by a SQUID. Due to their excellent energy resolution as well as the very low threshold, MMCs are a key technology in the frame of the EMPIR-project "PrimA-LTD" aiming to measure decay spectra of several isotopes with unprecedented precision to enable activity standardization for medicine and industry. Within this project we designed three MMC based layouts optimized for measuring the spectra of α-, β- and electron capture-decaying nuclides. We further developed a novel electroplating setup for the microfabrication of highly pure, 3D-structured particle absorbers made of Au to enable fast thermalization of the detector without position dependencies. Moreover, we started to develop a passive persistent current switch for injecting the persistent current allowing for easier detector handling and higher integration density in comparison to conventionally used heat switches. We summarize the present state of the project and outline ongoing next steps.

TT 31.10 Thu 15:00 P1

PrimA-LTD: Towards new primary activity standardization methods based on low-temperature detectors — •Alexander Göggelmann[1], Joern Beyer[2], Christian Enss[3,6], Sebastian Kempf[4,6], Karsten Kossert[1], Martin Loidl[5], Michael Müller[4], Ole Nähle[1], Michael Paulsen[2], Philipp Chung-On Ranitzsch[1], Matias Rodrigues[5], and Mathias Wegner[4,6] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt (PTB), Berlin, Germany — [3]Kirchhoff-Institute for Physics, Heidelberg University, Germany — [4]Institute of Micro- and Nanoelectronic Systems, Karlsruhe Institute of Technology, Karlsruhe, Germany — [5]CEA, LIST, Laboratoire National Henri Bequerel, Saclay, France — [6]Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, Karlsruhe, Germany

Radionuclide metrology, and in particular, activity standardization, is based on well-established measurement techniques that have been used and improved for decades. The methods and the achievable uncertainty are, however, very dependent on the type of radiation that is emitted and the quality of the available decay data. A major part of the EMPIR project "PrimA-LTD" consists in developing new primary techniques and in particular the high-resolution spectrometry of ^{241}Am, ^{129}I and ^{55}Fe using magnetic microcalorimeters (MMCs). The presentation will focus on the experimental details including the MMC detector setup, sample preparation and planned spectral measurements with more than 108 counts and energy thresholds below 50 eV.

TT 31.11 Thu 15:00 P1

Fabrication process for Nb/Al-AlO$_x$/Nb Josephson tunnel junction based SQUIDs for magnetic microcalorimeter readout — •Martin Neidig, Paul Kahrmann, and Sebastian Kempf — Institute of Micro- and Nanoelectronic Systems, Karlsruhe Institute of Technology, Karlsruhe, Germany

Magnetic microcalorimeters (MMCs) are cryogenic particle detectors providing an excellent energy resolution, very fast signal rise time, an almost ideal linear detector response and a large dynamic range. These properties combined with a maturing fabrication process motivate the implementation of large MMC based detector arrays which poses the challenge of developing a suitable readout method. Small-scale arrays are typically readout using single-channel dc-SQUIDs with individual wiring, while large-scale arrays require a multiplexed readout scheme. One such multiplexing scheme is the microwave SQUID multiplexer which allows for the readout of hundreds of detectors via a common feedline. The realization of either readout method requires the use of SQUIDs and therefore a reliable fabrication process for high quality Josephson junctions.

For this purpose we established a fabrication process for Nb/Al-AlO$_x$/Nb based window-type Josephson tunnel junctions. Within this contribution, we outline the present status of our fabrication technology and, moreover, we discuss the performance of the fabricated junctions and results of our prototype dc-SQUIDs, which are presently used for several MMC based experiments.

TT 31.12 Thu 15:00 P1

Noise Thermometers for Milli-Kelvin Measurements in High Magnetic Fields and for Micro-Kelvin Temperatures — •Pascal Willer, Christian Ständer, Nathalie Probst, Sarah Philips, Andreas Reiser, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University.

To measure the temperature in the presence of high magnetic fields is one of the big challenges in solid state physics labs. We recently

started to construct a prototype of a cross-correlated, current sensing noise thermometer for mK-temperatures for application in high magnetic fields. The basic concept relies on the thermal movement of charge carriers in a resistor. DC-SQUIDs detect the corresponding noise signal which is then recorded via two identical but independent amplifier chains. The method of cross correlation is used to eliminate uncorrelated noise contributions from the amplifier chains. As resistor material we use an alloy of platinum and thungsten, $Pt_{92}W_8$, since this material is characterized by an extremely small temperature dependence of the electrical resistivity as well as the smallest magnetoresistance known to date. We show that this approach towards a relative primary thermometer for high magnetic fields is able to operate over a wide range of temperatures within less than 1% uncertainty.
Additionally, we developed a second noise thermometer based on an alloy of copper and silver called "CuSil" to measure down to μK-temperatures in the absence of magnetic fields.
We discuss the design and the necessary considerations of both thermometers and present first experimental results at mK temperatures.

TT 31.13 Thu 15:00 P1

Microprocessor controlled temperature measurement with Allen-Bradley-carbon- and Platinum-100-Sensors — •Jelko Seiboth and Andreas Wieck — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

This poster illustrates the setup of a device for the determination of temperatures between RT (294 K) and 4 K using Pt100 sensors and Allen-Bradley resistors with a RT value between 100 Ω and 1 kΩ. To measure the resistance, a Raspberry Pi with an analog-to-digital converter and upstream connected operational amplifiers is used. This combination provides a low price and easy further development.

The measurement is carried out with four-point technology, whereby, to reduce the temperature increase due to the electrical power consumed by the sensor, the supply of the Pt100 sensors is provided with constant current and that of the Allen-Bradley sensors with constant voltage. The device allows calibration for specific resistors and calculates the temperature from a polynomial fit function [1,2].

The determined value is shown on a display, recorded in a subsequently exportable file and output to a proportional connector with a voltage corresponding to the temperature. As the Raspberry Pi supports network connections via Ethernet and Wi-Fi, a remote retrieval or external database storage of the measurements may be implemented in the future. Calibration and temperature measurements were successfully taken to prove the functionality.

[1] B. Fellmuth, Guide to the Realization of the ITS-90. BIPM, 2018
[2] Star et al., J. Phys. [E] **2**, 257 (1969)

TT 31.14 Thu 15:00 P1

Characterization and optimization of different regenerator matrices on a single-stage pulse tube cryocooler — •Dominik Soare[1,2], Jack-André Schmidt[1,2], Bernd Schmidt[1,2], Jens Falter[2], and André Schirmeisen[1,2] — [1]Justus-Liebig University Giessen — [2]TransMIT GmbH

Closed-cycle cryocoolers have become an important cooling concept tool for scientific research at low temperatures [1]. We here focus on Gifford-McMahon (GM) type pulse tube cryocoolers (PTC), which offer long measurement periods and low maintenance. The regenerator of any regenerative cryocooler is essential for the cooling process [2]. The regenerator offers heat capacity as a storage for the gas temperature during the cooling cycle. It pre-cools or -heats the working gas and therefore the regenerator matrix is an important optimization factor.

The poster will display the influence of different regenerator matrices on the cooling performance of a single stage pulse tube cryocooler driven by a helium compressor with 2kW input power. Using the results, it is possible to get new insights of the optimization of the first stage of two-stage cryocoolers and therefore their overall cooling performance.

[1] R. Güsten et al., Nature 568 (2019) 357
[2] P. P. Steijaert, Thermodynamical aspects of pulse-tube refrigerators (1999) 10

TT 31.15 Thu 15:00 P1

Materials losses in superconducting circuits based on tantalum thin films — •Ritika Dhundhwal[1], Thomas Reisinger[1], Haoran Duan[2], Dirk Fuchs[1], Matthieu Le Tacon[1], Jasmin Aghassi-Hagmann[2], and Ioan M. Pop[1] — [1]Institut für Quantenmaterialien und technologien (IQMT), Karlsruher Institut für Technologie (KIT) — [2]Institut für Nanotechnologie (INT), Karlsruher Institut für Technologie (KIT)

Superconducting quantum circuits have very promising applications in the fields of quantum computing and detection. In general, their performance is limited by a variety of dissipation and noise sources. For mitigating these, the focus has been on improving microwave design and better fabrication processes. Another approach, recently in the spotlight, is to explore new materials entirely. One promising candidate superconducting material is Tantalum (Ta), which recently enabled record-breaking Transmon qubit lifetimes. However, there is a lack of conclusive evidence of the dominant loss mechanisms related to Ta. Here, we present a study of losses in epitaxial Ta films deposited using magnetron sputtering, with the aim of relating basic material properties and loss mechanisms. A variation in the deposition parameters (mainly substrate temperature) leads to structurally different films. We characterized these using high-resolution X-ray diffraction, scanning electron microscopy and measurements of the superconducting transition temperature. In addition, we fabricated lumped element resonators from the films using e-beam lithography and measured their quality factors as a function of photon number and temperature.

TT 31.16 Thu 15:00 P1

The Influence of Continuous Electric Bias Fields on the Dielectric Loss of Atomic Tunneling Systems — •Jan Blickberndt, Christian Ständer, Lukas Münch, Marcel Haas, Andreas Reiser, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg, Germany

The low temperature properties of amorphous solids are mainly determined by atomic tunneling systems (TSs), which are known to act as a major source of noise and decoherence in superconducting quantum devices. We investigate the non-equilibrium dielectric loss of atomic tunneling systems under the influence of continuous electric bias fields at very low temperatures. By measuring the quality factor of a microfabricated superconducting resonator, the dielectric loss of the sample is obtained. Simultaneously, an electric bias field can be applied via a cover electrode, which allows us to sweep TSs through resonance by modulating their energy splitting. Experimentally, we found that for slow changing bias fields, TSs are saturated by the driving field leading to a constant loss. For faster bias rates, more and more TSs are swept through resonance and therefore contribute to an increasing loss. In the limit of fast continuous bias sweeps relaxation in between consecutive crossings diminishes and multiple coherent Landau-Zener transitions are possible, reducing the loss back to the saturation limit. We are able to verify these experimental results with a Monte Carlo based numerical simulation that shows good qualitative agreement.

TT 31.17 Thu 15:00 P1

Electrically and Acoustically Biased Resonators for Investigations of Dielectric Low Temperature Properties of Amorphous Solids — •Christian Ständer, Jan Blickberndt, Joyce Glass, Benedikt Frey, Andreas Reifenberger, Andreas Fleischmann, Andreas Reiser, and Christian Enss — Kirchhoff Institute for Physics, Heidelberg University, D-69120 Heidelberg

The low temperature properties of amorphous solids are governed by atomic tunnelling systems, which can be described as two-level systems (TLS) with a distribution of their energy splitting E, as assumed by the phenomenological standard tunnelling model. Recent interest in these systems due to their deteriorative effects on the performance of superconducting quantum devices lead to novel experimental investigations of atomic tunnelling systems driven by novel measurement techniques.
We use newly designed microfabricated superconducting LC-resonators to study the dielectric rf-response of the amorphous sample in the presence of an electric bias field. A novel method of applying this electrical bias field was introduced to the resonators. Compared to previous experiments, the bias field is applied via an electrode placed above the resonator chip. We present first results of this new way of introducing a bias, which modifies the energy splitting E of a TLS.
In addition we tried to achieve a similar effect as with the electrical bias field with a mechanical strain field. To induce such a strain field, the amorphous substrate of the resonator chip was flexed by a piezo-actuator.

TT 31.18 Thu 15:00 P1

Quantum electrodynamics of cold deposited granular aluminum — •Ameya Nambisan[1], Dennis Rieger[2], Simon Günzler[1], Wolfgang Wernsdorfer[1,2,3], and Ioan M Pop[1,2] — [1]Institute for Quantum Materials and Technology (IQMT), Karlsruhe Institute of

Technology (KIT), Germany — [2]Physikalisches Institut (PHI), Karlsruhe Institute of Technology (KIT), Germany — [3]Institute Néel, CNRS Grenoble, France

In recent times, superconducting granular aluminium (grAl) has found increasing interest in the superconducting quantum circuits community because of its promising characteristics such as its tunable kinetic inductance, low microwave losses, high in-plane critical magnetic field, and a higher critical temperature compared with pure Al.

In general, the critical temperature of a grAl film depends on its resistivity until it reaches a superconducting-to-insulator transition. For samples evaporated at room temperature, a maximum of around 2.2K is reached for resistivity of about 1000 $\mu\Omega$. The critical temperature rises even above 3K when grAl is deposited on a substrate held at a lower temperature of 100K.

This project aims to answer the question of increased Tc, which is yet to be understood microscopically, and other consequences of cold deposition, such as how a generally smaller – while more homogeneous – grain size positively affects the electrodynamics of the film. The testbed used to characterise the electrodynamics are stripline resonators fabricated entirely from cold-deposited grAl, and measured in a cylindrical copper waveguide sample holder at cryogenic temperatures.

TT 31.19 Thu 15:00 P1

Compact high-kinetic inductance using stacked Josephson junctions — •Alex S. Kreuzer[1], Thilo Krumrey[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie (KIT) — [2]Institut für Quantenmaterialien und -technologien (IQMT), Karlsruher Institut für Technologie (KIT)

Highly inductive elements are often required in modern superconducting quantum circuits, e.g. to form, together with a suitable capacitance, a large non-dissipative impedance. One way of creating such a high inductance is to employ series arrays of Josephson junctions, as it is done in the fluxonium qubit. For conventionally made chains of Josephson junctions, a major limitation arises from the stray capacitance of the islands forming the junctions. This capacitance leads to undesirable parasitic resonances at GHz frequencies, which degrade the quantum coherence of the qubit.

We propose a new way of creating high-inductance elements by stacking Josephson junctions vertically thus avoiding the influence of the through-substrate capacitive coupling of the junction electrodes to the environment. Furthermore, we demonstrate that our approach allows for making extremely compact circuit components.

TT 31.20 Thu 15:00 P1

Towards machine learning models for NISQ processors — •Andras Di Giovanni[1], Hannes Rotzinger[1,2], Alexey V. Ustinov[1,2], Adrian Aasen[3], Moritz Reh[3], and Martin Gärttner[3] — [1]Karlsruhe Institute for Technology, Karlsruhe, Germany — [2]Institut für QuantenMaterialien und Technologien, Karlsruhe, Germany — [3]Heidelberg University, Heidelberg, Germany

Quantum simulators promise insights into quantum many-body problems in regimes where classical simulation methods hit a complexity wall. One challenge towards this goal is to develop well characterized building blocks that allow to scale up system sizes while conserving reliability in terms of errors. A promising platform for building such NISQ (noisy, intermediate-scale quantum) devices are superconducting quantum circuits. Our goal is to characterize small scale quantum processors with minimal experimental and post-processing cost. For this we implement schemes for machine learning assisted adaptive Bayesian tomography and apply them to experimental data obtained from a prototype few-qubit superconducting chip.

TT 31.21 Thu 15:00 P1

Exploring the parameter regimes of superconducting Quarton qubits coupled via cross-Kerr nonlinearity — •Hossam Tohamy[1], Alex Siegfried Kreuzer[1], Thilo Krumrey[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany

Over the last two decades, tremendous efforts have been directed into studying superconducting qubits as a promising architecture for noisy intermediate-scale quantum processors to implement quantum simulations and algorithms. A recent superconducting qubit named the "Quarton" represents a generalized flux qubit featured by a quartic potential profile. It can offer positive, strong cross-Kerr nonlinearity compared to the ordinary linear dispersive coupling between qubits and resonators. This nonlinearity can be essential, e.g., to achieve the next milestones in quantum simulation, such as the simulation of model Hamiltonians where strong photon-photon interactions are possible via nonlinear elements.

To employ the quarton as a qubit and a coupler, a system of two primary quarton qubits coupled via a quarton qubit coupler is studied. We report on numerical results demonstrating the normal modes of the system. The calculations are based on a Hamiltonian derived from a circuit quantization model. The work is linked to ongoing experimental efforts for realizing multiqubit architecture based on quartons.

TT 31.22 Thu 15:00 P1

Multilayer surface acoustic wave resonators at cryogenic temperatures — •Alexander Jung[1,2], Thomas Luschmann[1,2,3], Achim Marx[1], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik-Department, Technische Universitaet Muenchen, Garching, Germany — [3]Munich Center for Quantum Science and Technologies (MCQST), Munich, Germany

Circuit quantum acoustodynamics uses the piezoelectric coupling of surface acoustic waves (SAW) to superconducting qubits for the implementation of concepts known from circuit quantum electrodynamics [1,2]. In this approach, the role of electromagnetic field is replaced by an acoustic wave propagating at the speed of sound. Moreover, the wavelength of acoustic waves is of the order of the size of the artificial atom, and thus their interaction with the qubit can no longer be treated pointlike. SAW resonators are an essential building block for quantum acoustodynamics. Of particular interest is the integration of SAWs using a piezoelectric on a silicon substrate to combine highly coherent qubits with excellent SAW properties. However, this changes the properties of the SAWs in particular for thin piezoelectric films. Here, we present simulations and experimental studies of SAW resonators fabricated on bulk and thin film piezoelectric substrates at cryogenic temperatures to understand the SAW as multilayer system.

[1] A.F.Kockum, International Symposium on Mathematics, Quantum Theory, and Cryptography (2021)
[2] Mathematics for Industry, 33, 125 (2020)

TT 31.23 Thu 15:00 P1

Flux-pumped Josephson Traveling Wave Parametric Amplifier — •Daniil E. Bazulin[1,2], Kedar E. Honasoge[1,2], Leon Koch[1,2], Yuki Nojiri[1,2], Thomas Luschmann[1,2], Achim Marx[1], Stefan Filipp[1,2,3], and Kirill G. Fedorov[1,2] — [1]Walther-Meißner-Institut, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Development of scalable superconducting quantum computers requires an efficient read-out of multiple quantum bits. This goal can be achieved by exploiting broadband Josephson Traveling Wave Parametric Amplifiers (JTWPAs). These are typically based on arrays of superconducting nonlinear elements, such as various types of Superconducting Quantum Interference Devices (SQUIDs). Here, we report on fabrication and characterization of a specific type of the JTWPA based on aluminium asymmetric SQUIDs exploiting the three-wave mixing down-conversion process. With this approach we circumvent inherent JTWPA problems with phase-matching and are able to spatially separate signal and pump paths.

TT 31.24 Thu 15:00 P1

Measurement of single NV centers inside a solid immersion lens at mK temperature — •Amer Hasecic, Ioannis Karapatzakis, Marcel Schrodin, Rainer Kraft, and Wolfgang Wernsdorfer — Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Deutschland

A solid immersion lens (SIL) prevents refraction on a diamond-air surface and therefore increases the collection efficiency of detected photons [1]. SILs are nanofabricated by removing bulk material via focused ion beam technique. Here, we rely on accelerated gallium ions. The photon collection from single Nitrogen-Vacancy (NV) centers inside a solid immersion lens in bulk diamond is examined at mK temperatures. We aim to improve readout times for electron spin and nuclear spin states with the later being a promising system in quantum computing [2].

[1] M. Jamali, Rev. Sci. Instrum. 85, 123703 (2014)
[2] M. Abobeih, Nature (2022)

TT 31.25 Thu 15:00 P1

Quantum manipulation of NV centers in diamond with on-chip coplanar waveguides at mK temperatures — •Ioannis Karapatzakis, Amer Hasecic, Marcel Schrodin, Rainer Kraft, and Wolfgang Wernsdorfer — Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Deutschland

Quantum information technology is advancing in several physical fields. Optically addressable spins such as Nitrogen-Vacancy (NV) centers in the solid-state structure of diamond stand out for their versatile applications in quantum mechanics which range from quantum processing of information [1] to magnetic field sensing [2]. NV centers can be reliably initialized optically and have long coherence and relaxation times.

Here, the quantum manipulation of NV centers is shown inside a dilution refrigerator (sionludi) at mK temperatures. Using lithographically fabricated on-chip coplanar waveguide circuits, Rabi oscillations can be driven with frequencies above 100 MHz at comparatively low microwave insertion power of 100 mW (20 dBm). This allows for fast manipulation of the NV center spin states at mK temperatures without excessive heating of the sample.

[1] A. Tsukanov, Russian Microelectronics 41, 91 (2012)
[2] L. Rondin, Reports on Progress in Physics 77, 056503 (2014)

TT 31.26 Thu 15:00 P1

Navigation system for a low temperature STM — •Timo Kandra, Roman Hartmann, Marcel Strohmeier, Sara Khorshidian, and Elke Scheer — University of Konstanz, Germany

To obtain spatially resolved spectroscopic information in laterally confined superconducting heterostructures, such as nanowires and flakes on insulating substrates, tunneling spectroscopy on distinct locations on those structures shall be performed. For this purpose a coarse approach system is needed that allows to locate the STM tip at the point of interest without crashing the tip and while operating at very low temperature, here, 300 mK. We developed a braille-like pattern that allows to determine the absolute position of the tip within a 100x100 μm^2 scan range by scanning any area of size 1x1μm^2. The search structure made of gold is patterned by electron beam lithography and is realized by a topographical pattern composed of squares. With this method it is possible to navigate to the point of interest by using an xy-table.

TT 32: Focus Session: Topological Devices (joint session TT/KFM)

The properties of topological phases of matter give rise to unique phenomena, such as edge or surface transport, spin-momentum locking, or topological protection against perturbations. Many years after their conception, several topological platforms have reached maturity, and research interests have shifted towards mesoscopic devices unveiling rich and new topological physics, driven in part by the perspectives of novel topological quantum computation. Within this Focus Session, recent examples of devices exploring or exploiting the topological properties of various phases of matter shall be discussed.

Organizers: Erwann Bocquillon, Oliver Breunig, Yoichi Ando (all Universität zu Köln)

Time: Thursday 15:00–18:30 Location: H10

Invited Talk TT 32.1 Thu 15:00 H10

Supercurrents in HgTe-based topological nanowires — •Dieter Weiss — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg/Germany

Topological insulator (TI) nanowires in proximity to conventional superconductors constitute a tunable platform to realize topological superconductivity and Majorana zero modes [1]. Tuning is done by an axial magnetic flux ϕ transforming the system from trivial at $\phi = 0$ to topologically nontrivial when a magnetic flux quantum $\phi_0 = h/2e$ threads the wire's cross-section. Here, we investigate the evolution of the supercurrent in ballistic HgTe Josephson junctions as a function of axial magnetic flux ϕ and examine the periodicity of the supercurrent utilizing microwave irradiation and probing Shapiro steps. Suppressed odd Shapiro steps herald the existence of 4π-periodic supercurrents, a signature of topological superconductivity. Our data suggest that at small ϕ this 4π-periodic supercurrent is of trivial origin but that at magnetic fields above $\phi_0/2$, topological 4π-periodic supercurrents take over [2].

Work done in cooperation with Ralf Fischer, Wolfgang Himmler, Johannes Ziegler, Jordi Picó-Cortés , Gloria Platero, Milena Grifoni, Dmitriy A. Kozlov, N. N. Mikhailov, Sergey A. Dvoretsky , Michael Barth, Jakob Fuchs, Cosimo Gorini, Klaus Richter, and Christoph Strunk.

[1] A. Cook and M. Franz, PRB 84, 201105(R) (2011)
[2] R. Fischer et al., PRR 4, 013087 (2022)

Invited Talk TT 32.2 Thu 15:30 H10

Majorana bound states and non-reciprocal transport in topological insulator nanowire devices — •Henry Legg — Department of Physics, University of Basel

I consider devices consisting of a three-dimensional topological insulator (TI) nanowire placed in proximity to an s-wave superconductor.

First, I will show that a non-uniform chemical potential induced, for instance, by gating enables the device to be brought into a topological superconducting phase at relatively weak magnetic fields with Majorana bound states (MBSs) present for an exceptionally large region of parameter space in realistic systems. I also consider the experimental challenges posed by the metallization effect that occurs as a result of bringing a TI nanowire into proximity with a superconductor.

Second, I will discuss non-reciprocal transport evidence for the subband splitting that is central to the proposal to achieve MBSs in TI nanowires. I will show that a giant magnetochiral anisotropy observed in the normal state of the TI nanowire provides strong evidence for the artificial breaking of inversion symmetry due to gating effects. Furthermore, I will argue that the superconducting diode effect can be used as measure of inversion symmetry breaking in the presence of a superconductor and to determine when the TI nanowire is in the region of parameter space where topological superconductivity is expected.

Invited Talk TT 32.3 Thu 16:00 H10

Integration of topological insulator Josephson junctions in superconducting qubit circuits — •Tobias W. Schmitt[1], Malcolm R. Connolly[2,3], Michael Schleenvoigt[1], Chenlu Liu[2], Oscar Kennedy[3], José M. Chávez-Garcia[4], Anne Schmidt[1], Albert Hertel[1], Tobias Lindström[5], Sebastian E. de Graaf[5], Karl D. Petersson[4], Detlev Grützmacher[1], and Peter Schüffelgen[1] — [1]Peter Grünberg Institute & Jülich-Aachen Research Alliance, Forschungszentrum Jülich — [2]Blackett Laboratory, Imperial College London — [3]London Centre for Nanotechnology, University College London — [4]Center for Quantum Devices, University of Copenhagen — [5]National Physical Laboratory

Since the prediction of topological superconductivity in hybrid devices of topological insulators (TIs) and conventional s-wave superconductors (S), S-TI-S Josephson junctions have been studied intensively in electrical transport experiments. The integration of these Josephson junctions in superconducting qubit circuits allows to investigate them via circuit quantum electrodynamic techniques, which promises novel insights into their exotic characteristics. In this talk, I will present the implementation of transmon qubits with *in situ* fabricated S-TI-S Josephson junctions and outline fabricational challenges. I will further show results on coherent qubit control as well as temporal quantum coherence and discuss possible limitations on qubit coherence for the first generation of TI transmon devices [1]. An outlook on qubit improvements and developements towards the detection of topological superconductivity will be given.

[1] Nano Lett. 22, 7, 2595 (2022)

15 min. break

Invited Talk TT 32.4 Thu 16:45 H10

Universal fluctuations of the induced superconducting gap in an elemental nanowire — Lauriane Contamin, Lucas Jarjat, William Legrand, Audrey Cottet, Takis Kontos, and •Matthieu Delbecq — Laboratoire de Physique de l'Ecole Normale Supérieure, ENS, Université PSL, CNRS, Sorbonne Université, Université Paris-Diderot, Sorbonne Paris Cité, Paris, France.

Proximity induced superconductivity in a normal conductor is a rich field of experimental and theoretical investigations. Lately it has been at the heart of the quest for realizing topological modes in hybrid superconductor-nanowire nanodevices. Yet it turns out that there was a lack of investigations in elemental systems. In this work we therefore investigate an ultra-clean carbon nanotube coupled to a superconducting lead. We observe for the first time a long standing prediction of random matrix theory (RMT) that mesoscopic fluctuations of the mini-gap in a conductor follow a universal distribution with a clear transition when time reversal symmetry is broken, as predicted by RMT. Interestingly, mesoscopic fluctuations of the minigap were precisely predicted to lead to ubiquitous nontopological edge states clustering towards zero energy. We do indeed observe ubiquitous and robust zero bias conductance peaks under magnetic field in our device that cannot host topological modes by design. The RMT predictions that are compatible with our observations are very general and should be present in any system showing disorder. It therefore calls for alternatives to transport measurement to identify Majorana modes in 1D systems with microwave photons in a cavity as a promising platform.

Invited Talk TT 32.5 Thu 17:15 H10

Exploring the full potential of edge channel transport in HgTe based two-dimensional topological insulators — •Saquib Shamim[1,2], Wouter Beugeling[1,2], Pragya Shekhar[1,2], Jan Böttcher[3], Andreas Budewitz[1,2], Julian-Benedikt Mayer[3], Lukas Lunczer[1,2], Jonas Strunz[1,2], Johannes Kleinlein[1,2], Ewelina Hankiewicz[3], Björn Trauzettel[3], Hartmut Buhmann[1,2], and Laurens Molenkamp[1,2] — [1]Experimentelle Physik III, Physikalisches Institut, Universität Würzburg, Am Hubland, Würzburg, Germany — [2]Institute for Topological Insulators, Universität Würzburg, Am Hubland, Würzburg, Germany — [3]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany.

In this talk, I will discuss some of our recent results on HgTe-based two-dimensional topological insulators. Over the past few years, we have developed a chemical wet-etch technique to fabricate high-quality microstructures in HgTe quantum wells. Firstly, I will discuss some important achievements due to the wet-etch fabrication process: We fabricated quantum point contacts in topological HgTe quantum wells and investigated the interactions among helical edge channels. We also fabricated microstructures from (Hg,Mn)Te quantum wells and observed quantized conductance in these devices. Secondly, I will introduce a gate training method that allows us to approach conductance quantization in macroscopic devices. Finally, I will present recent magnetotransport results on (Hg,Mn)Te quantum wells and the emergence of quantum Hall plateaus at extremely low magnetic fields (~ 50 mT).

TT 32.6 Thu 17:45 H10

Quantum non-Hermitian topological sensors — •Florian Koch and Jan Carl Budich — Institute of Theoretical Physics, Technische Universität Dresden

Recent discoveries regarding the exceptional spectral and topological properties of non-Hermitian (NH) tight-binding models, e.g. their striking boundary-sensitivity, have triggered the quest for constructing novel sensors [1,2]. Here, using quantum master equations we promote the architecture of such sensing devices to a fully quantum-mechanical framework. Specifically, we study a setting of weakly-coupled bosonic modes arranged in an array with broken ring geometry that would realize a NH topological phase in the classical limit. Employing methods from quantum-information theory of Gaussian states, we show that a small coupling induced between the ends of the broken ring may be detected with a precision that increases exponentially in the number of coupled modes. Our findings pave the way towards designing quantum NH topological sensors (QUANTOS) that may observe with high precision any physical observable that couples to the boundary conditions of the device [3].

[1] J.C. Budich and E.J. Bergholtz, Phys. Rev. Lett. **125**, 180403 (2020).
[2] E.J. Bergholtz, J.C. Budich, and F.K. Kunst, Rev. Mod. Phys. **93**, 015005 (2021).
[3] F. Koch and J.C. Budich, Phys. Rev. Res. **4**, 013113 (2022).

TT 32.7 Thu 18:00 H10

First magnetic field measurements of a topological insulator based Transmon Qubit — •Anne Schmidt[1], Tobias W. Schmitt[1], Chenlu Liu[2], Albert Hertel[1], Christian Dickel[3], Michael Schleenvoigt[1], Malcolm R. Connolly[2,4], Yoichi Ando[3], Detlev Grützmacher[1], and Peter Schüffelgen[1] — [1]Peter Grünberg Institute & Jülich-Aachen Research Alliance, Forschungszentrum Jülich — [2]Blackett Laboratory, Imperial College London — [3]Institute of Physics II, University of Cologne — [4]London Centre for Nanotechnology, University College London

Hybrid topological insulator (TI) – superconductor (S) heterostructures are a promising platform for the realization of topologically protected quantum computation based on Majorana zero modes. This promises fewer physical qubits for creating a logical qubit compared to conventional superconducting qubits. Our full *in situ* device fabrication, which combines selective area growth of thin $(Bi,Sb)_2Te_3$ films and stencil deposition of superconductive Nb has already shown to create highly transparent S-TI interfaces. Recently, we have demonstrated that this fabrication process can readily be integrated into cQED structures as building block for a transmon qubit and performed coherence measurements at zero magnetic field. Here, we will expand these measurements to finite magnetic fields, as in-plane magnetic fields are a requirement for restoring the topological phase in confined $(Bi,Sb)_2Te_3$ nanostructures. We present initial results on the magnetic field dependence of the T_1 lifetime and the qubit's anharmonicity.

TT 32.8 Thu 18:15 H10

Kondo interactions of quantum spin Hall edge channels with charge puddles — •Christopher Fuchs[1,2], Pragya Shekhar[1,2], Saquib Shamim[1,2], Lena Fürst[1,2], Johannes Kleinlein[1,2], Jukka I. Väyrynen[3], Hartmut Buhmann[1,2], and Laurens W. Molenkamp[1,2] — [1]Physikalisches Institut, Universität Würzburg, Würzburg, Germany — [2]Institute for Topological Insulators, Universität Würzburg, Würzburg, Germany — [3]Department of Physics and Astronomy, Purdue University, West Lafayette, USA

Quantum spin Hall edge channels are protected against backscattering by time-reversal symmetry. However, since the first observation of the quantum spin Hall effect in HgTe in 2007 it is known that reproducible fluctuations shape the quantization plateau when the chemical potential is tuned through the bulk gap. Here, those fluctuations are examined in high-quality micron-sized quantum well structures of HgTe at millikelvin temperatures. By performing temperature and gate-dependent measurements, we conclude that the observed conductance fluctuations indicate interactions of the edge channel electrons with individual charge puddles – microscopic fluctuations in the potential landscape commonly observed in narrow gap semiconductors – that act like Kondo correlated quantum dots. The resulting spin-flip backscattering gives rise to a distinct Kondo-like temperature dependence of the conductance fluctuations, which is backed up by theoretical modelling. Our results provide insight into the leading mechanism of decoherence of quantum spin Hall edge channels.

TT 33: Nonequilibrium Quantum Many-Body Systems (joint session TT/DY)

Time: Thursday 15:00–18:15 Location: H22

TT 33.1 Thu 15:00 H22

Investigating the non-equilibrium dynamics of two-level systems at low temperature — •Marcel Haas, Mareike Dinger, Lukas Münch, Jan Blickberndt, Andreas Reiser, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg, Germany

The dielectric loss of amorphous materials along with noise and decoherence is the major limiting factor in many applications like superconducting circuits, Josephson junctions and quantum computing. It is mainly determined by atomic tunneling systems described by quantum mechanical two-level systems (TLS), which are broadly distributed low-energy excitations in the sample. The spontaneous phonon emission of an excited TLS gives rise to a relaxation time T_1 and the interaction between TLSs with their thermally excited surrounding induces a decoherence time T_2. These effects mainly determine the measurable dielectric loss in the observed material, which we ascertain by measuring the quality factor of a bridge type superconducting LC-resonator. The dielectric medium in between the capacitor plates is a sputter deposited a-SiO_2 film. The setup shows a unique property when two off-resonant pump tones are applied symmetrically. In this limit, the resonator is emitting at the intermediate frequency of the driving fields. The underlying mechanism can therefore be explained by a nonlinear interaction of the rf-field with the TLSs and the resonator which is creating additional lines in the frequency spectrum. We present first measurements at a frequency of 1 GHz performed with a micro-fabricated superconducting resonator.

TT 33.2 Thu 15:15 H22

Photoinduced prethermal order parameter dynamics in the two-dimensional large-N Hubbard-Heisenberg model — •Alexander Osterkorn and Stefan Kehrein — University of Göttingen, Göttingen, Germany

A central topic in current research in non-equilibrium physics is the design of pathways to control and induce order in correlated electron materials with time-dependent electromagnetic fields. The theoretical description of such processes, in particular in two spatial dimensions, is very challenging and often relies on phenomenological modelling in terms of free energy landscapes. We discuss a semiclassical time evolution scheme that includes dephasing dynamics beyond mean-field and allows to simulate the light-induced manipulation of prethermal order in a two-dimensional model [1] with competing phases microscopically. We calculate the time evolution of the relevant order parameters subsequent to driving with a short laser pulse [2]. The induced prethermal order does not depend on the amount of absorbed energy alone but also explicitly on the driving frequency and amplitude. While this dependency is pronounced in the low-frequency regime, it is suppressed at high driving frequencies.

[1] Phys. Rev. B 39, 11538 (1989)
[2] arXiv:2205.06620

TT 33.3 Thu 15:30 H22

Nonequilibrium dynamics in pumped Mott insulators — •Satoshi Ejima[1], Florian Lange[2], and Holger Fehske[1,2] — [1]Institut für Physik, Universität Greifswald, Greifswald, Germany — [2]Erlangen National High Performance Computing Center, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

The study of systems under optical excitation receives tremendous attention because of both the recent rapid developments of ultrafast pump lasers and the discovery of striking phenomena not observable in equilibrium. Various numerical techniques have been applied to optically excited systems to study nonequilibrium dynamics, e.g., the time-dependent version of exact-diagonalization technique or dynamical mean-field theory. Results for nonequilibrium dynamics based on tensor-network algorithms are still rare, however.

In this talk, we propose a direct numerical scheme in the matrix-product-states (MPS) representation for the computation of nonequilibrium dynamic response functions, which can be used for general (quasi-)one-dimensional systems. Using time-evolution techniques for (infinite) MPS, we calculate, directly in the thermodynamic limit, the time-dependent photoemission spectra and dynamic structure factors of the half-filled Hubbard chain after pulse irradiation. These quantities exhibit clear signatures of the photoinduced phase transition from insulator to metal that occurs because of the formation of so-called η pairs.

[1] S. Ejima et al., Phys. Rev. Res. **2**, 032008(R) (2020)
[2] Phys. Rev. Res. **4**, L012012 (2022)
[3] arXiv:2204.09085

TT 33.4 Thu 15:45 H22

Nonequilibrium non-Markovian steady states in open quantum many-body systems: Persistent oscillations in Heisenberg quantum spin chains — •Regina Finsterhoelzl[1], Manuel Katzer[2], and Alexander Carmele[2] — [1]Department of Physics, University of Konstanz, Germany — [2]Institute of Theoretical Physics, Technical University Berlin, Germany

We investigate the effect of a non-Markovian, structured reservoir on an open Heisenberg spin chain by applying coherent time-delayed feedback control to it. The structured reservoir couples frequency-dependent to the spin chain and therefore induces a memory, thus the spin chain interacts partially with its own past. We demonstrate that with this new paradigm of a non-Markovian temporal driving scheme, it is possible to generate persistent oscillations within the many-body system and thus induce highly non-trivial states which dynamically store excitation within the chain. These oscillations occur at special points in the stability landscape and persist for different chain lengths and different initial excitations within the chain. We propose a non-invasive partial characterization of the chain by exploiting the fact that the different trapping conditions which arise each relate to specific steady states within the chain.

TT 33.5 Thu 16:00 H22

Approaching the time-dependent quantum many-body problem with Artificial Neural Networks — •Pit Neitemeier and Dante Kennes — RWTH Aachen Institut für Theorie der statistischen Physik

Numerical solutions to quantum many body problems pose a significant challenge due to the curse of dimensionality. In this work I propose a novel Artificial Neural Network (ANN) ansatz and an unsupervised learning scheme to efficiently and flexibly solve time dependent quantum many-body problems. Contrary to previous work I do not rely on ODE Solvers for the time evolution, but parametrize the full wave function using an ANN. This enables a constant cost evaluation and full differentiablity of the wave function. Furthermore I show that it is possible to learn solution bundles that continuously represent the solution for a range of external parameters. The training of these ANNs is highly parallelizeable and reduces sequential operations significantly in comparison to previous work. I benchmark the ansatz for quantum quenches, ramps and pulses of the magnetic field using 1D Ising and Heisenberg Chains.

TT 33.6 Thu 16:15 H22

Entanglement phase transitions in correlated 1D spin chains — •Monalisa Singh Roy, Jonathan Ruhman, Emanuele G. Dalla Torre, and Efrat Shimshoni — Department of Physics, Bar-Ilan University, Ramat Gan 5290000, Israel

Entanglement phase transitions have attracted immense attention in recent years especially in the context of monitored quantum circuits. In such systems the dynamics due to unitary evolution compete with the localization induced by measurements. The phase transition of quantum systems from a phase where its entanglement entropy exhibits volume law for weak monitoring, to a quantum Zeno like phase with where the entanglement entropy obeys area law is well known in many models with unitary dynamics. Some recently proposals have identified a critical phase with a logarithmic scaling of entanglement in non-Hermitian models. We explore such a critical transition in a monitored quantum spin chain model and identify the entanglement transitions in the system under both unitary and non-unitary evolutions.

TT 33.7 Thu 16:30 H22

Feynman-Vernon influence functional approach to quantum transport in interacting nanojunctions: An analytical hierarchical study — •Luca Magazzu and Milena Grifoni — University of Regensburg

We present a nonperturbative and formally-exact approach to the charge transport in interacting nanojunctions using a real-time path-integral method based on the Feynman-Vernon influence functional. Expansion of the influence functional in terms of the number of tunneling transitions results in an exact generalized master equation for the populations in the occupation-number representation, and in a formally exact expression for the current. We apply our method to the exactly solvable resonant level model (RLM) and to the single-impurity Anderson model (SIAM). 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. Using a simplified fourth-tier scheme, analytical results for the interacting SIAM are presented both in equilibrium and nonequilibrium and with an applied magnetic field.
[1] L. Magazzù and M. Grifoni, Phys. Rev. B 105, 125417 (2022)

15 min. break

TT 33.8 Thu 17:00 H22

In-Gap Band Formation in a Periodically Driven Charge Density Wave Insulator — •Alexander Osterkorn, Constantin Meyer, and Salvatore Manmana — University of Göttingen, Göttingen, Germany

Periodically driven quantum many-body systems host unconventional behavior not realized at equilibrium. Here we investigate such a setup for strongly interacting spinless fermions on a chain, which at zero temperature and strong interactions form a charge density wave insulator. Using unbiased numerical matrix product state methods for time-dependent spectral functions, we find that driving of the correlated charge-density wave insulator leads not only to a renormalization of the excitation spectrum as predicted by an effective Floquet Hamiltonian [1], but also to a cosine-like in-gap feature [2]. This is not obtained for a charge density wave model without interactions. A mean-field treatment provides a partial explanation in terms of doublon excitations. However, the full picture needs to take into account strong correlation effects. [1] Phys. Rev. Lett. 120, 127601 (2018) [2] arXiv:2205.09557

TT 33.9 Thu 17:15 H22

Non-equilibrium phases of matter in 2D using Projected Entangled Pair States — •Augustine Kshetrimayum[1,2], Dante Kennes[3], and Jens Eisert[1,2] — [1]Freie University Berlin, Germany — [2]Helmholtz-Zentrum Berlin, Germany — [3]RWTH Aachen University, Germany

We explore the highly challenging realm of non-equilibrium physics in two spatial dimensions using infinite Projected Entangled Pair States (iPEPS), a two-dimensional tensor network ansatz directly in the thermodynamic limit. By adding disorder in a translationally invariant setting through the use of auxiliary states, we find evidence of Many-body localization (MBL) and Quantum time crystals in 2D.

In our discrete disorder setting, we show that many levels of disorder is required in order to achieve localization and ultimately time crystalline behavior. We discuss how our setting can be realized in programmable quantum simulators.

TT 33.10 Thu 17:30 H22

Charge transport in hybrid semiconductor-cavity systems: an exact diagonalization study — •Sebastian Stumper and Junichi Okamoto — Institute of Physics, University of Freiburg, Freiburg, Germany

Recent experiments demonstrate that the conductivity of organic semiconductors can be enhanced by hybridization with a plasmonic surface [Nat. Mat. 14, 1123 (2015)]. Motivated by these findings, we study a two-band tight-binding chain resonantly coupled to a photonic mode by an exact diagonalization technique. First, we argue that the exciton density and photon number are suppressed by the band gap, an effect which is neglected by the commonly used rotating wave approximation. Second, we determine the excitation of the semiconductor and its impact on the conductivity beyond the rotating wave approximation, i.e., including the off-resonant terms. Clean and disordered cases are compared. Finally, we discuss the real-time dynamics of electrons and holes under a uniform electric field.

TT 33.11 Thu 17:45 H22

Interplay of disorder and interactions in a periodically driven ultracold atomic system — •Arijit Dutta — Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt am Main, Germany

Periodically driven clean noninteracting systems are known to host several interesting topological phases. Particularly, for high frequency driving, they have been found to host the analogues of equilibrium topological phases, like the Haldane phase. However, upon lowering the driving frequencies these systems have been found to host anomalous phases with robust edge modes despite all Chern numbers being zero. Moreover, theoretical works have shown that adding disorder to such anomalous phases leads to quantized charge pumping through the edge modes even when all bulk states become localised. We investigate the fate of these phases in presence of electron-electron interactions of the Falicov-Kimball type.

TT 33.12 Thu 18:00 H22

Non-equilibrium optical conductivity for striped states: A time-dependent Gutzwiller analysis for the single-band Hubbard model — •Christian Martens and Götz Seibold — BTU Cottbus-Senftenberg, Institute of Physics, 03046 Cottbus, Germany

In recent years pump-probe experiments have turned out as a powerful tool to investigate the dynamics of correlated materials, e.g. transition metals or heavy fermion systems. In these experiments the system is prepared in a non-equilibrium state by a strong laser pulse, where the relaxation is afterwards examined by standard optical techniques. This method has also been applied to stripe ordered nickelates and cuprate superconductors where it allows to study the coupled order-parameter dynamics of charge- and spin-density waves and superconductivity.

Here we use the time-dependent Gutzwiller approximation for the single-band Hubbard model to analyse the non-equilibrium dynamics for stripe ground states of different symmetry. In particular we are interested in the interplay between spin and charge dynamics which is analysed by quenching the system in the charge or spin sector. This allows us to investigate the coupled relaxation dynamics as a function of the inserted energy. In contrast to the Hartree-Fock + random-phase-approximation the optical conductivity shows high-energy double occupancy fluctuations in addition to the low-energy collective mode. In the out-of equilibrium regime we find a softening of both modes depending on the inserted energy. Moreover the double occupancy exitation broadens into a continuum.

TT 34: Correlated Electrons: Theory 2

Time: Thursday 15:00–18:45 Location: H23

TT 34.1 Thu 15:00 H23

The fate of the spin polaron in the 1D t-J model — •Piotr Wrzosek — Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Pasteura 5, PL-02093 Warsaw, Poland

We study the intrinsic origin of the well-established differences in the motion of a single hole in the 1D and 2D antiferromagnet. To this end, we consider a 1D t-J model, perform the slave fermion transformation to the holon-magnon basis, and solve the obtained model in a numerically exact manner. We explicitly show that the spin polaron quasiparticle, which is well-known from the studies of a single hole in the 2D antiferromagnet, is destroyed in the 1D t-J model by the magnon-magnon interactions. Nevertheless, we observe surprising similarities between the spectra obtained with and without magnon-magnon interactions, indicating that some of the key features of the spin polaron physics are still preserved in 1D.

TT 34.2 Thu 15:15 H23

Huge enhancement of the thermal conductivity in the Tomonaga-Luttinger-liquid region of $YbAlO_3$ — •Parisa Mokhtari[1,2], Ulrike Stockert[1], and Elena Hassinger[1,2] — [1]Max-Planck-Institute for Chemical Physics of Solids, Dresden, Germany — [2]Physics Department, Technical University of Munich, Garching, Germany

In 2019, Wu et al. found the typical excitation spectrum of the spinons in the Q-1D material $YbAlO_3$ via neutron scattering at 1 K. $YbAlO_3$ exhibit AFM (J_c=2.3 K) and FM (J_ab=0.8 K) exchange interaction along and perpendicular to the chain direction, respectively [1, 2]. In zero field, a 3D AFM order is established at 0.88 K. For fields along a, perpendicular to the chain, this order is suppressed and replaced by an IC-AFM state, until the FI-FM state occurs for B >1.5 T.

It is an open question, if magnetic excitations in this material carry heat, and how they interact with phonons. Hence, we investigate the low-T κ of $YbAlO_3$ down to 30 mK in fields up to 4 T. The phase diagram is successfully reproduced with pronounced anomalies in both T and B sweeps. A clear additional anomaly in the field dependence at low T confirms a crossover within the IC phase, which was suggested before based only on a tiny plateau appearing in the magnetisation. We find a large variation of the κ throughout the phase diagram indicating strong magneto-elastic coupling. In addition, a substantial enhancement of kappa is observed in the proposed TLL region.

[1] L. S. Wu et al., Nat. Commun. 10, 698 (2019)
[2] L. S. Wu et al., Phys. Rev. B 99, 195117 (2019)

TT 34.3 Thu 15:30 H23

Counting statistics in interacting one-dimensional conductors — •Oleksiy Kashuba[1], Roman Riwar[1], Fabian Hassler[2], and Thomas Schmidt[3] — [1]Forschungszentrum Jülich — [2]RWTH Aachen — [3]Luxemburg Uni

The calculation of the cumulant generating function of a given observable, such as the charge, is nontrivial even for the non-interacting systems. This problem is closely connected to the problem of Toeplitz eigenvalues and the Szego-Kac theorem [1]. The application of the latter leads to a violation of the moment generating function's periodicity along the counting field. This periodicity can be restored using the Fisher-Hartwig conjecture, as was shown for non-interacting one-dimensional electrons [2]. Here, we aim to go beyond and include interactions. For weak interactions, a modification of the Matsubara diagrammatic approach was developed, allowing us explicit calculation of the interaction corrections to the cumulant generating function. All obtained terms preserve the periodic constraint of the moment generating function. The obtained result is in a good agreement at low filling with the noise suppression in Luttinger liquid for K<1. We also found a surprising counterpart of the charge-density wave effect in the cumulant generating function.

[1] Basor, Morrison, Linear Algebra and its Appl. 202 (1994), 129
[2] Aristov, Phys. Rev. B 57 (1998), 12825

TT 34.4 Thu 15:45 H23

Enhancement of pair correlations in the asymmetric Hubbard ladder — •Anas Abdelwahab and Eric Jeckelmann — Leibniz Universität Hannover, Hannover, Germany

We investigated an extension of the asymmetric two-leg Hubbard ladder model [1,2] that consists of different on-site interaction U_y and intra-hopping t_y on each leg y using the density matrix renormalization group method. We calculated pair binding energy, charge, spin and single particle gaps as well as pairing correlation functions for several sets of model parameters. It is possible to adjust the asymmetry of model parameters to retain finite pair binding energy and enhanced pairing correlation functions similar to those appearing in symmetric two-leg Hubbard ladders. Such adjustment represents an interpolation between doped Mott insulator and doped charge transfer insulator.

[1] A. Abdelwahab, E. Jeckelmann, M. Hohenadler, Phys. Rev. B 91, 155119 (2015)
[2] A. Abdelwahab and E. Jeckelmann, Eur. Phys. J. B 91, 207 (2018).

TT 34.5 Thu 16:00 H23

Magnetic properties of a quantum spin ladder material in proximity to the isotropic limit — •Sergei Zvyagin — Dresden High Magnetic Field Laboratory (HLD-EMFL), Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

We report on the synthesis, crystal structure, magnetic, thermodynamic, and electron-spin-resonance properties of the coordination complex $[Cu_2(pz)_3(4\text{-}HOpy)_4](ClO_4)_4$ [pz = pyrazine; 4-HOpy = 4-hydroxypyridine] [1]. This material is identified as a spin-1/2 Heisenberg ladder system with exchange-coupling parameters $J_{\rm rung}/k_B$ = 12.1(1) K and $J_{\rm leg}/k_B$ = 10.5(3) K [$J_{\rm rung}/J_{\rm leg}$ = 1.15(4)]. For single crystals our measurements revealed two critical fields, $\mu_0 H_{c1} = 4.63(5)$ T and $\mu_0 H_{c2} = 22.78(5)$ T (for $H \parallel a^*$), separating the gapped spin-liquid, gapless Tomonaga-Luttinger-liquid, and fully spin-polarized phase. No signature of a field-induced transition into a magnetically ordered phase was found at temperatures down to 450 mK. The material bridges an important gap by providing an excellent physical realization of an almost isotropic spin-1/2 strong-rung Heisenberg ladder system with modest exchange-coupling energy and critical-field scales.

[1] S. A. Zvyagin, A. N. Ponomaryov, M. Ozerov, E. Schulze, Y. Skourski, R. Beyer, T. Reimann, L. I. Zviagina, E. L. Green, J. Wosnitza, I. Sheikin, P. Bouillot, T. Giamarchi, J. L. Wikara, M. M. Turnbull, and C. P. Landee, Phys. Rev. B **103**, 205131 (2021)

TT 34.6 Thu 16:15 H23

Finite-temperature optical conductivity with density-matrix renormalization group methods for the Holstein polaron and bipolaron with dispersive phonons — •David Jansen[1], Janez Bonča[2,3], and Fabian Heidrich-Meisner[1] — [1]Institute for Theoretical Physics, University of Göttingen — [2]J. Stefan Institute, Ljubljana — [3]Faculty of Mathematics and Physics, University of Ljubljana

We compute the optical conductivity for the Holstein polaron and bipolaron with dispersive phonons at finite temperature using a matrix-product state based method. We combine purification [1], to obtain the finite-temperature states, together with the parallel time-dependent variational principle (pTDVP) [2] algorithm to compute the real time current-current correlation functions. The pTDVP algorithm utilizes local basis optimization [3] to efficiently treat the phononic degrees of freedom. For the polaron, we find that the phonon dispersion alters the optical conductivity at several temperatures in the weak, intermediate, and strong coupling regime. In the two first cases, we see that the spectrum goes from being continues to discrete when going from a downwards to a upwards phonon dispersion. In the strong coupling regime, the dispersion leads to a shift of the center of the spectrum. For the bipolaron, we study the effect of dispersion in both the weak and strong electron-phonon coupling regime, and thus see its influence on both a delocalized and a localized bipolaron.

This research was supported by the DFG via SFB 1073.

[1] Verstraete et al., Phys. Rev. Lett. 93, 207204 (2004)
[2] Secular et al., Phys. Rev. B 101, 235123 (2020)
[3] Zhang et al., Phys. Rev. Lett. 80, 2661 (1998)

TT 34.7 Thu 16:30 H23

Cavity-induced long-range interactions in strongly correlated systems — •Paul Fadler[1], Jiajun Li[2], Kai Phillip Schmidt[1], and Martin Eckstein[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Paul Scherrer Institut

In recent years, the coupling of optical cavity modes to solid states systems has emerged as a possible way to control material properties. Here we investigate cavity-induced long-range interactions between spins in a Mott insulator, which are a new feature of the coupling to the quantized cavity field, and are absent in a control of magnetism by classical light. In detail, for the Fermi-Hubbard model at half filling we show that the cavity coupling leads to long-range four-spin terms in the effective low spin model at large onsite interaction U, in addition to the conventional antiferromagnetic Heisenberg exchange interaction.

To obtain these long-range interactions, we compare exact diagonalization, a perturbative approach based on the effective spin-photon Hamiltonian description of the system, and fourth-order perturbation theory in the Hubbard model. We show that the phenomenologically motivated spin-photon Hamiltonian fails to describe the interactions properly close to resonances of the cavity and charge excitations. It is therefore not possible to perturbatively treat cavity coupled correlated systems in an effective spin basis.

15 min. break

TT 34.8 Thu 17:00 H23

Magnetism and Mottness in the anisotropic triangular lattice Hubbard model: a cellular dynamical mean-field study — •Marcel Klett[1], Henri Menke[2], Michel Ferrero[3], Antoine Georges[3], and Thomas Schäfer[1] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]University of Erlangen-Nuremberg, Erlangen, Germany — [3]College de France, Paris, France

We investigate the phase diagram of the anisotropic triangular lattice Hubbard model in a center-focused cellular dynamical mean-field theory (CDMFT) approach using an impurity with 7 sites. We investigate the Mott metal-to-insulator transition and crossover region as well as the superconducting phase. Using a spin symmetry-broken approach of the CDMFT, allowing for a rotations of spins on the Bloch sphere, we are able to investigate the magnetic ordering of the different cluster schemes.

TT 34.9 Thu 17:15 H23

Competing orders in a two-dimensional Su-Schrieffer-Heeger model — •Anika Götz[1], Martin Hohenadler[1,2], and Fakher Assaad[1,3] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, 97074 Würzburg, Germany — [2]Independent Researcher, Josef-Retzer-Str. 7, 81241 Munich, Germany — [3]Würzburg-Dresden Cluster of Excellence ct.qmat, Am Hubland, 97074 Würzburg, Germany

We study a two-dimensional Su-Schrieffer-Heeger model of electrons coupled to Einstein phonons with auxiliary-field quantum Monte Carlo simulations. By adding a symmetry-allowed interaction, the phonons can be integrated out at the expense of imaginary-time correlations of the discrete Hubbard-Stratonovich fields. Using single spin-flip updates, we investigate the phase diagram at the O(4)-symmetric point as a function of hopping t and phonon frequency ω_0. For low phonon frequencies, the C_4 lattice symmetry is broken by valence bond order. Depending on t, the ordering wavevector is either (π, π) or $(\pi, 0)$, the latter value being accompanied by a dynamically generated π-flux in each plaquette. At larger ω_0, the O(4) symmetry is spontaneously broken by long-range antiferromagnetic (AFM) order. In the limit $t \to 0$, the model maps onto an unconstrained Z_2 gauge theory coupled to fermions which is in its confined phase for the parameters considered. Whereas the $(\pi, 0)$-VBS to AFM transition is a candidate for a deconfined quantum critical point, the details of the $(\pi, 0)$-VBS to (π, π)-VBS and (π, π)-VBS to AFM transitions are still under investigation.

TT 34.10 Thu 17:30 H23

Splitting of topological charge pumping in an interacting two-component fermionic Rice-Mele Hubbard model — •Eric Bertok[1], Fabian Heidrich-Meisner[1], and Armando A. Aligia[2] — [1]Institute for Theoretical Physics, Georg-August-Universität Göttingen — [2]Centro Atómico Bariloche and Instituto Balseiro, Bariloche, Argentina

A Thouless pump transports an integer amount of charge when pumping adiabatically around a singularity. We study the splitting of such a critical point into two separate critical points by adding a Hubbard interaction. Furthermore, we consider extensions to a spinful Rice-Mele model, namely a staggered magnetic field or an Ising-type spin coupling, further reducing the spin symmetry. The resulting models additionally allow for the transport of a single charge in a two-component system of spinful fermions, whereas in the absence of interactions, zero or two charges are pumped. In the SU(2)-symmetric case, the ionic Hubbard model is visited once along pump cycles that enclose a single singularity. Adding a staggered magnetic field additionally transports an integer amount of spin while the Ising term realizes a pure charge pump. We employ real-time simulations in finite and infinite systems to calculate the adiabatic charge and spin transport, complemented by the analysis of gaps and the many-body polarization to confirm the adiabatic nature of the pump. The resulting charge pumps are expected to be measurable in finite-pumping speed experiments in ultra-cold atomic gases. We discuss the implications of our results for a related quantum-gas experiment by Walter et al. [arXiv:2204.06561].

TT 34.11 Thu 17:45 H23

Thermodynamics of the metal-insulator transition in the extended Hubbard model from determinantal quantum Monte Carlo — •Alexander Sushchyev and Stefan Wessel — RWTH Aachen University

We use finite-temperature determinantal quantum Monte Carlo simulations to study the thermodynamic properties of the extended Hubbard model on the square lattice at half-filling. In particular, we consider the effect of a nearest-neighbor and a long-range Coulomb repulsion on the thermal metal-insulator transition in the Slater regime at intermediate coupling. Within the parameter regime accessible to sign-free quantum Monte Carlo simulations we explore in detail the temperature dependence of the double occupancy and entropy. Notably, we probe for signatures of a first-order metal-insulator transition driven by the suppression of correlation effects by the non-local interactions, as proposed in [1].

[1] M.Schueler et al., Sci. Post. Phys. 6, 067 (2019)

TT 34.12 Thu 18:00 H23

Surrogate models for quantum spin systems based on reduced order modelling — •Stefan Wessel[1], Michael Herbst[1], Benjamin Stamm[1], and Matteo Rizzi[2] — [1]RWTH Aachen University — [2]University of Cologne and FZ Jülich

We present a methodology to investigate phase-diagrams of quantum spin models based on the principle of the reduced basis method. It is based on constructing a low-dimensional basis built from solutions of snapshots, i.e., ground states corresponding to particular and well-chosen parameter values. We propose to use a greedy-strategy to assemble the reduced basis and thus to select the parameter points where the full model is solved. Once the reduced basis is computed, observables required for the computation of phase-diagrams can be computed with a computational complexity independent of the underlying Hilbert space for any parameter value. We illustrate the accuracy of this approach for a geometrically frustrated antiferromagnetic two-dimensional lattice model and quantum spin model that describes a chain of excited Rydberg atoms.

TT 34.13 Thu 18:15 H23

Bound by three-body interactions — •Gary Ferkinghoff[1], Leanna Müller[1], Umesh Kumar[2], Götz S. Uhrig[1], and Benedikt Fauseweh[3] — [1]Condensed Matter Theory, Technische Universitat Dortmund, Otto-Hahn-Straße 4, 44227 Dortmund, Germany — [2]Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA — [3]Institute for Software Technology, German Aerospace Center (DLR), Linder Hohe, 51147 Cologne, Germany

Stable bound quantum states are ubiquitous in nature. Mostly, they result from the interaction of only pairs of particles, so called two-body interactions, even when complex many-particle structures are formed. We show that three-quasi-particle bound states occur in a generic, experimentally accessible solid state system: antiferromagnetic spin ladders, related to high-temperature superconductors. Strikingly, this binding is induced by genuine three-quasi-particle interactions; without them there is no bound state. We compute the dynamic exchange structure factor required for the experimental detection of the predicted state by resonant inelastic x-ray scattering for realistic material parameters. Our work enables us to quantify these elusive interactions and unambiguously establishes their effect on the dynamics of the quantum many-particle state. In this talk we will present the main results of our study, briefly explain the theoretical tools that we used and present an experimental setting for verifying our theoretical results.

TT 34.14 Thu 18:30 H23

Non-linear response functions and disorder: The case of the photo galvanic effect — •Konstantinos Ladovrechis and Tobias

Meng — Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

The circular photogalvanic effect (CPGE) is a non-linear photocurrent which is generated in materials with broken inversion symmetry when they are shed with circularly polarised light. In Weyl semi-metals, the CPGE is quantized in terms of fundamental constants and the Chern numbers associated with the Weyl nodes. In this work, we investigate the effect of pointlike disorder onto the quantization of CPGE. Implementing 1st-order and self-consistent Born approximations, we identify that the quantization of CPGE is broken and perturbative corrections in the scattering strength emerge, which we further classify in terms of self-energy and vertex corrections.

TT 35: Members' Assembly

Time: Thursday 19:00–20:00 Location: H22

All members of the Low Temperature Physics Division are invited to participate.

TT 36: Focus Session: Ultrafast Spin, Lattice and Charge Dynamics of Solids

This focus session deals with a current and interdisciplinary topic, which is of interest to many researchers in solid state physics. The focus is on the generation and manipulation of new effects such as switching the macroscopic magnetic order, the driving of metal-insulator transitions, and the observation of purely quantum mechanical phenomena in excited states (e.g., the squeezing of phonons) on the femtosecond time scale using laser pulses. The long-term goal is the coherent control of degrees of freedom in solids. The relevant issues are light-matter interaction on the ultrashort time scale, non-equilibrium dynamics of magnetic, phononic and electronic degrees of freedom, many-particle physics and strong correlations.

Organizers:

Davide Bossini, University of Konstanz and Götz S. Uhrig, TU Dortmund University

Time: Friday 9:30–12:15 Location: H10

Invited Talk TT 36.1 Fri 9:30 H10

Coherent control of lattice and electronic states — •Steven Johnson — ETH Zurich, Zurich, Switzerland — Paul Scherrer Institut, Villigen, Switzerland

In this presentation I discuss a selection of recent efforts to use ultrafast light pulse excitation ranging from near-infrared to THz wavelengths to achieve control over both structural and electronic degrees of freedom in condensed phase materials. In one example, ultrafast excitation of a quasi-2D material results in a large-scale coherent modulation of structure (as seen by femtosecond x-ray diffraction) and associated carrier effective masses. These modulations are strongly connected to a nearby topological phase transition. In another example I discuss experiments uisiing high field THz pulses to drive both coherent and incoherent carrier dynamics in a narrow-gap semiconductor, and describe how these dynamics can be inferred from multidimensional THz spectroscopy. The results demonstrate that carrier multiplication effects become dominant at moderately intense field strengths. In the final example I will discuss ongoing efforts to use combinations of high- and low-frequency light excitation to drive nonlinear structural dynamics in a soft mode ferroelectric.

Invited Talk TT 36.2 Fri 10:00 H10

New opportunities for light-matter control of quantum materials — •Michael Sentef — Max Planck Institute for the Structure and Dynamics of Matter, Hamburg

In this talk I will discuss recent progress in controlling and inducing materials properties with light [1]. Specifically I will discuss recent experiments showing light-induced superconducting-like optical responses through phonon driving in an organic kappa salt [2], and their possible theoretical explanation via dynamical Hubbard U [3]. I will then highlight some recent theoretical and experimental progress in cavity quantum materials [4,5], where the classical laser as a driving field of light-induced properties is replaced by quantum fluctuations of light in confined geometries. Ideas and open questions for future work will be outlined.

[1] Rev. Mod. Phys. 93, 041002 (2021)
[2] Phys. Rev. X 10, 031028 (2020)
[3] Phys. Rev. Lett. 125, 137001 (2020)
[4] Applied Physics Reviews 9, 011312 (2022)
[5] J. Phys. Mater. 5, 024006 (2022)

Invited Talk TT 36.3 Fri 10:30 H10

Coherent electronic control of an insulator-to-metal transition — •Claudio Giannetti, Paolo Franceschini, and Alessandra Milloch — Università Cattolica del Sacro Cuore, Brescia (Italy)

Managing light-matter interaction on timescales faster than the loss of electronic coherence is key for achieving the full quantum control of final products in solid-solid transformations. Here, we demonstrate coherent electronic control of the photoinduced insulator-to-metal transition in the prototypical Mott insulator V_2O_3. Selective excitation of a specific interband transition with two phase-locked light pulses manipulates the orbital occupation of the correlated bands in a way that depends on the coherent evolution of the photoinduced superposition of states.

Comparison between experimental results and numerical solutions of the optical Bloch equations indicates an electronic coherence time on the order of 5 fs. Temperature dependent experiments suggest that the electronic coherence time is enhanced in the vicinity of the insulator-to-metal transition critical temperature, thus highlighting the role of fluctuations in determining the electronic coherence. These results open new routes to selectively switch functionalities of quantum materials and store quantum information in solid-solid transformations.

15 min. break

Invited Talk TT 36.4 Fri 11:15 H10

Nanoscale transient magnetization dynamics: A comprehensive EUV TG study — •Laura Foglia — Elettra Sincrotrone Trieste, Trieste, Italy

The advent of X-ray free electron lasers (FELs) has allowed to overcome the wavelength limitations of optical radiation to manipulate and study magnetic phenomena on nanometer length- and femtosecond time-scale, which is paramount for light-controlled ultrafast magnetic data processing and storage applications. In this talk, we review the most recent advances on the EUV TG-based investigation of nanoscale transient magnetization dynamics, a technique pioneered at the FERMI FEL in Trieste, Italy. First, we show how EUV-TG is capable of inducing transient magnetization gratings which decay within tens of picoseconds via thermal diffusion. Building upon this first demonstration, we investigate the transition from ultrafast demagnetization to all-optical switching (AOS) by looking at the ratio between the first and the second order of diffraction as a function of excitation fluence. Indeed, the non-linear fluence dependence of AOS induces a non-uniform spacing of the magnetization pattern that results in the appearance of even diffraction orders. Finally, we compare the magnetization dynamics induced by intensity gratings with those launched by polarization gratings, obtained when the two excitation beams have orthogonal polarization. Here, the intensity distribution on the sample is uniform and ultrafast the formation of transient magnetization gratings has to be associated to the coupling of majority and minority spins with the electric field polarization.

Invited Talk TT 36.5 Fri 11:45 H10

Ultrafast magnetism of antiferromagnets — •Alexey Kimel — Radboud University, Nijmegen, The Netherlands

Antiferromagnets are ideal candidates to reach the THz landmark in data storage with no additional energy costs. However, the lack of a net magnetization in the antiferromagnetic ground state requires exceedingly high magnetic fields to manipulate the spins, hindering even fundamental studies on the control and switching of antiferromagnets. Here we propose an approach to empower THz control of antiferromagnetic order by pushing antiferromagnet out of equilibrium through a generation of coherent magnonic states. We will show that an antiferromagnet out of equilibrium is practically a different material. Generation of coherent magnonic states in antiferromagnets substantially modifies the susceptibility of antiferromagnetic spins to THz magnetic fields and facilitates energy transfer between otherwise noninteracting phononic and magnonic modes [1,2]. In this case, the generated impact on spins goes far beyond trivial superposition of excitations and can facilitate conceptually new ways for controlling antiferromagnetism. The proposed theoretical description suggests that spin dynamics in antiferromagnets is intrinsically non-linear and once coherent magnonic state is induced, additional channels of energy transfer between otherwise orthogonal modes open up.

[1] E. A. Mashkovich, K. Grishunin, R. Dubrovin, R. V. Pisarev, A. K. Zvezdin and A. V. Kimel, Science 374, 1608 (2021)
[2] Th. Blank et al. (in preparation)

TT 37: Superconducting Electronics: SQUIDs, Qubits, Circuit QED

Time: Friday 9:30–13:15 Location: H22

TT 37.1 Fri 9:30 H22

Nb constriction Josephson junctions and nanoSQUIDs patterned by He and Ne focused ion beams — •Simon Pfander[1], Timur Griener[1], Julian Linek[1], Thomas Weimann[2], Ute Drechsler[3], Reinhold Kleiner[1], Armin Knoll[3], Oliver Kieler[2], and Dieter Koelle[1] — [1]Physikalisches Institut, Center for Quantum Science (CQ) and LISA$^+$, Universität Tübingen, 72076 Tübingen, Germany — [2]Department Quantum Electronics, Physikalisch-Technische Bundesanstalt (PTB), 38116 Braunschweig, Germany — [3]IBM Research Europe – Zürich, 8803 Rüschlikon, Switzerland

Nanopatterning of superconducting thin film structures with focused He or Ne ion beams (He/Ne-FIB) offers a flexible tool for creating constriction-type Josephson junctions (cJJs) and strongly miniaturized superconducting quantum interference devices (nanoSQUIDs) for magnetic sensing on the nanoscale. We present our attempts to use He/Ne-FIB for fabricating Nb cJJs and nanoSQUIDs which shall provide ultra-low noise and high spatial resolution for their application in scanning SQUID microscopy (SSM). The nanoSQUIDs are designed as sensors for magnetic flux and dissipation. They shall be integrated on custom-made Si cantilevers, which will provide the possibility of simultaneous conventional topographic imaging by atomic force microscopy (AFM). We will discuss the status of this project and challenges that have to be met on the way to combine SSM and AFM on the nanoscale.

We acknowledge the European Commission under H2020 FET Open grant FIBsuperProbes (number 892427).

TT 37.2 Fri 9:45 H22

Development of a three-wave-mixing Josephson traveling-wave parametric amplifier — •Victor Gaydamachenko[1], Christoph Kissling[1,2], Lukas Grünhaupt[1], Ralf Dolata[1], and Alexander B. Zorin[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Technische Universität Ilmenau, Germany

Modern quantum experiments profit from wideband amplification of small microwave signals with noise approaching the quantum-limit. A promising approach to design an amplifier having a bandwidth of several GHz, power gain of 20 dB, and quantum-limited noise are traveling-wave parametric amplifiers (TWPAs). We develop a Josephson traveling-wave parametric amplifier (JTWPA), based on a series array of 1500 rf-SQUIDs, and utilising the three-wave mixing regime. One of the main challenges of TWPAs is power leakage to unwanted processes like the generation of higher harmonics and mixing products, which significantly limit the gain. To solve this obstacle, we apply a dispersion engineering technique. Here, we present numerically optimised parameter sets for practical realisation of our concept. Simulations of the device operation show a signal gain of 20 dB in the frequency range from 3 GHz to 9 GHz.

TT 37.3 Fri 10:00 H22

Charge-mediated quantum phase slip interference — •Jan Nicolas Voss[1], Micha Wildermuth[1], Max Kristen[1,2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Institut für Quantenmaterialien und Technologien (IQMT), Karlrsruher Institut für Technologie, Karlsruhe, Germany

The duality between quantum phase slip junctions and Josephson junctions has triggered a variety of theoretical and experimental works and set the basis for a new type of quantum device based on coherent quantum phase slips. We present a realization of a quantum phase slip interferometer based on two strongly coupled superconducting nanowires. The interference is controlled by a gate voltage and visible as a periodic modulation of the critical Coulomb blockade voltage. The strength of the modulation strongly depends on the homogeneity of the wires, as the phase slip rates exponentially depend on the normal state resistances of the wires. We use the intrinsic electromigration technique ([1]) to adjust and homogenize the resistances of the wires in-situ and therefore are able to study a large range of wire impedances for single devices.

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

TT 37.4 Fri 10:15 H22

RF superconducting arbitrary waveform generator for Qubit control — •Hao Tian, Oliver Kieler, Alexander Fernandez Scarioni, Silke Wolter, Rolf-Werner Gerdau, Johannes Kohlmann, and Mark Bieler — Physikalisch Technische Bundesanstalt

The Josephson Arbitrary Waveform Synthesizer (JAWS) allows for the quantum-accurate-generation of spectrally-pure, arbitrary waveforms. It consists of a series array of Josephson junctions and is driven by GHz bit sequences (current pulses). So far, JAWS circuits are mainly used at National Metrology Institutes for metrological purposes with output frequencies in the kHz to MHz frequency range. Within the scope of the national QuMIC project, PTB and other partners are currently further developing JAWS circuits with the aim to realize a compact and robust module, which is suitable for control and readout of superconducting qubits. In this talk, we will present the work, which is currently undertaken at PTB to reach this goal. Here, the main focus lies on the design and the fabrication of novel JAWS circuits and complex waveguide filters, capable of synthesizing arbitrary waveforms at GHz frequencies. This work was partly supported by German Federal Ministry of Education and Research (contract number: 13N15934).

TT 37.5 Fri 10:30 H22

Gate-tunable kinetic inductance in proximitized nanowires — •Lukas Johannes Splitthoff[1], Arno Bargerbos[1], Lukas Grünhaupt[1], Marta Pita-Vidal[1], Jaap Joachim Wesdorp[1], Yu Liu[2], Angela Kou[3], Christian Kraglund Andersen[1], and Bernard van Heck[4] — [1]Delft University of Technology, Delft University of Technology, Delft, The Netherlands — [2]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark — [3]Department of Physics and Frederick Seitz Materials Research Laboratory, University of Illinois Urbana-Champaign, Urbana, USA — [4]Leiden Institute of Physics, Leiden University, Leiden, The Netherlands

Superconducting-semiconducting nanowires combine two frontiers of condensed matter in a hybrid state, which offers formidable possibilities for quantum computing and quantum sensing devices. In this talk, we study a quarter-wave coplanar waveguide resonator shunted by a hybrid InAs/Al nanowire. We show a gate voltage controllable resonance frequency and demonstrate a frequency shift of up to 8MHz. We relate the frequency shift to the change in kinetic inductance of the hybrid nanowire which arises from the gate-tunable hybridization of the superconductor to semiconductor interface. From our measurement results we extract the normal state conductivity and the superconducting gap of the hybrid nanowire. The measurement technique demonstrated in this work complements existing characterization methods for hybrid nanowires and forms a promising path towards gate-controlled superconducting electronics.

TT 37.6 Fri 10:45 H22

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 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. The ability to employ band-structure design techniques together with the unique properties of compactness, reduced speed of light, and strong non-linear features allows the design of highly versatile on-chip microwave networks. Furthermore utilizing this platform, we present first theoretical device proposals of linear and non-linear functional units, such as beamsplitters, filters, resonators and diodes exploiting non-reciprocity.

[1] S. Goldstein, G. Pardo, N. Kirsh, N. Gaiser, C. Padurariu, B. Kubala, J. Ankerhold, and N. Katz, New J. Phys. 24 023022 (2022)

TT 37.7 Fri 11:00 H22

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], Yuri Mukharsky[3], Zubair Iftikhar[3], Carles Altimiras[3], Patrice Roche[3], Helene le Sueur[3], Philippe Joyez[3], Denis Vion[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 [1]. 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 larger Josephson coupling E_J, a more complex behavior is observed in quantitative agreement with numerical simulations. 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.

[1] G. C. Menard, et al., Phys. Rev. X **12**, 021006 (2022).

TT 37.8 Fri 11:15 H22

Waveguide quantum electrodynamics in high impedance networks — •Miriam Resch[1], 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

The emerging field of high impedance quantum circuits aims to exploit the extraordinary properties of high kinetic inductance materials, such as granular superconductors. The low propagation speed of electromagnetic excitations in such devices enables to strongly couple sub-units of quantum information devices, namely various types of qubits or resonators and waveguides. Theoretical description of such strongly coupled systems is challenging as the localized modes of the sub-unit typically couples to many waveguide modes simultaneously so that many common approximation schemes break down. While strong-coupling effects in closed systems have been widely investigated, showing, e.g. the breakdown of the Jaynes-Cummings model, our project aims at describing strongly coupled open quantum systems and photon emission. With experimental collaborators, we ultimately want to identify strong-coupling signatures in observables of the emitted radiation. Here, we present as preliminary steps towards the description of more complicated systems first investigations based on an ansatz, where the wave function of the complete system (unit + waveguide) is described by superposition of coherent states as proposed in [1], which allows to solve the system dynamics in a numerically efficient way.

[1] Nicolas Gheeraert et al., New J. Phys. 19 (2017) 023036

15 min. break

TT 37.9 Fri 11:45 H22

Fano interference in microwave resonator measurements — •Simon Günzler[1,2], Dennis Rieger[2], Martin Spiecker[1,2], Wolfgang Wernsdorfer[1,2], and Ioan Pop[1,2] — [1]IQMT, Karlsruhe Institute of Technology, Germany — [2]PHI, Karlsruhe Institute of Technology, Germany

Resonator measurements are a simple but powerful tool to characterize a material's microwave response. The losses of a resonant mode are quantified by its internal quality factor Q_i, which can be extracted from the scattering coefficient in a microwave reflection or transmission measurement. Here we show that a systematic error on Q_i arises from Fano interference of the signal with a background path. Limited knowledge of the interfering paths and their relative amplitudes in a given setup translates into a range of uncertainty for Q_i, which increases with the coupling coefficient. We experimentally illustrate the relevance of Fano interference in typical microwave resonator measurements and the associated pitfalls encountered in extracting Q_i. On the other hand, we show how to characterize and utilize the Fano interference to eliminate the systematic error.

TT 37.10 Fri 12:00 H22

Direct observation of microscopic tow-level systems in granular aluminum films — •Maximillian Kristen[1,2], Jan N. Voss[2], Micha Wildermuth[2], Andre Schneider[2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Institut für QuantenMaterialien und Technologien (IQMT), Karlsruher Institut für Technologie — [2]Physikalisches Institut, Karlsruher Institut für Technologie

Thin films of disordered superconductors are extensively studied due to their applicability in quantum circuits and detectors, where they can provide kinetic inductances orders of magnitude higher than their geometric inductance. While these films generally show very high quality factors in microwave measurements, their disordered microscopic structure favors the presence of numerous material defects behaving as two-level systems (TLS). TLS have been shown to be a major source of dielectric loss in microwave circuits and are limiting the coherence properties of modern superconducting qubits.

We present microwave spectroscopy measurements of resonators made from highly resistive granular aluminum films. By applying mechanical strain and electric fields, we observe several TLS strongly interacting with the resonator modes. We compare the measured data to an analytical model for the single-photon interaction with TLS and estimate relevant physical properties.

TT 37.11 Fri 12:15 H22

Magnetic 1/f noise in superconducting microstructures and the fluctuation-dissipation theorem — •M. Herbst, A. Fleischmann, L. Gastaldo, D. Hengstler, L. Münch, A. Reifenberger, C. Ständer, and C. Enss — Uni Heidelberg

The performance of superconducting devices like SQUIDs and qubits is often limited by 1/f-noise and finite coherence times. Various types of slow fluctuators in the Josephson-junctions and in the passive parts of these superconducting circuits can cause such noise, and devices most likely suffer from a combination of different noise sources, which are hard to disentangle and therefore hard to eliminate. Magnetic flux noise caused by fluctuating magnetic moments of magnetic impurities or dangling bonds in superconducting inductances, surface oxides, insulating oxide layers and adsorbates should be a very likely contribution in many cases. We present an experimental setup to measure at Millikelvin temperatures both, the complex impedance of superconducting micro-structures as well as the magnetic flux noise that is picked-up by these structures. This allows for very important sanity checks by connecting both quantities via the fluctuation-dissipation-theorem. In order to allow for state-of-the-art sensitivity in both experiments, the structures under investigation are part of a Wheatstone-like bridge, read-out by two cross-correlated independent dc-SQUID readout chains. We present measurements of the insulating SiO2 layers of our devices, the superconducting structures themselves, and magnetically doped noble-metal layers in the vicinity of the pickup coils at T = 20-800mK and f=100mHz-100kHz.

TT 37.12 Fri 12:30 H22

A quantum Szilard engine for two-level systems coupled to a qubit — •Martin Spiecker[1], Patrick Paluch[1], Niv Drucker[2], Shlomi Matityahu[1], Daria Gusenkova[1], Nicolas Gosling[1], Simon Günzler[1], Dennis Rieger[1], Ivan Takmakov[1], Francesco Valenti[1], Patrick Winkel[1], Richard Gebauer[1], Oliver Sander[1], Gianluigi Catelani[3], Alexander Shnirman[1], Alexey V. Ustinov[1], Wolfgang Wernsdorfer[1], Yonatan Cohen[2], and Ioan M. Pop[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Quantum Machines, Tel Aviv-Yafo, Israel — [3]Forschungszentrum Jülich, Jülich, Germany

The innate complexity of solid state physics exposes superconducting quantum circuits to interactions with uncontrolled degrees of freedom degrading their coherence. By using a simple stabilization sequence we show that a superconducting fluxonium qubit is coupled to a two-level system (TLS) environment of unknown origin, with a relatively long energy relaxation time exceeding 50ms. Implementing a quantum Szilard engine with an active feedback control loop allows us to decide whether the qubit heats or cools its TLS environment. The TLSs can be cooled down resulting in a four times lower qubit population, or they can be heated to manifest themselves as a negative temperature environment corresponding to a qubit population of 80%. We show that the TLSs and the qubit are each other's dominant loss mechanism and that the qubit relaxation is independent of the TLS populations. Mitigating TLS environments is therefore not only crucial to improve qubit lifetimes but also to avoid non-Markovian qubit dynamics.

TT 37.13 Fri 12:45 H22

Green's function approach to modelling finite size systems for applications in superconducting waveguide QED — •Pradeepkumar Nandakumar[1], Andres Rosario Hamann[1,2], Rohit Navarathna[1], Maximilian Zanner[3], Mikhail Pletyukhov[4], and Arkady Fedorov[1] — [1]ARC Centre of Excellence for Engineered Quantum Systems, School of Mathematics and Physics, The University of Queensland, Saint Lucia, Queensland 4072, Australia — [2]Department of Physics, ETH Zurich, CH-8093 Zurich, Switzerland — [3]Center for Quantum Physics, and Institute for Experimental Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [4]Institute for Theory of Statistical Physics, RWTH Aachen University, 52056 Aachen, Germany

In superconducting waveguide QED, artificial atoms are coupled to a 1D radiation channel that consists of continuum of electromagnetic modes. Waveguides are often modelled as infinite in size with open boundary conditions for the ease of understanding. However, while modelling waveguides employed in experiments, one should consider both the finite size of the waveguide as well as its coupling to measurement apparatus. To this end, we have developed a general method to realistically model any waveguide QED system using the Green's function methods that is often employed in studying electronic transport. We apply our formalism and experimentally study the formation of Atom-Photon Bound States (APBS) using two transmon qubits coupled to a 3D rectangular waveguide. Our results identify the prospects for using APBS for studying bosonic impurity models.

TT 37.14 Fri 13:00 H22

Dirac physics and charge localization due to quasiperiodic nonlinear capacitances — •Tobias Herrig[1], Jedediah Pixeley[2], Elio König[3], and Roman-Pascal Riwar[1] — [1]Forschungszentrum Jülich, Germany — [2]Rutgers University, Piscataway, New Jersey, USA — [3]Max-Planck Institute, Stuttgart, Germany

Superconducting circuits are an extremely versatile platform to realize quantum information hardware, and, as was recently realized, to emulate topological materials, such as Weyl semimetals or Chern insulators. We here show how a simple arrangement of capacitors and conventional SIS junctions can realize a nonlinear capacitive element with a suprising property: it can be quasiperiodic with respect to the quantized Cooper-pair charge. Integrating this element into a larger circuit opens the door towards the engineering of an even broader class of systems. First, we use it to simulate a protected Dirac material defined in the transport degrees of freedom. The presence of the Dirac point leads to a suppression of the classical part of the finite-frequency noise. Second, we are able to exploit the quasiperiodicity to implement the Aubry-André model, and therebey to emulate Anderson localization in charge space. Our setup implements a truly non-interacting version of the model, in which the macroscopic quantum mechanics of the circuit already incorporates microscopic interaction effects. This should be contrasted to conventional solid state and cold atomic realizations, where competition between interaction and localization are a common side effect. We predict that quantum charge fluctuations directly probe the localization effect.

TT 38: Superconductivity: Theory

Time: Friday 9:30–11:00 Location: H23

TT 38.1 Fri 9:30 H23

Unconventional superconductivity in the Hubbard model on the pyrochlore lattice — Shingo Kobayashi[1], Ankita Bhattacharya[2], •Carsten Timm[2], and Philip M. R. Brydon[3] — [1]RIKEN Center for Emergent Matter Science, Saitama, Japan — [2]TU Dresden, Germany — [3]University of Otago, Dunedin, New Zealand

The Hubbard model on the pyrochlore lattice is studied close to half filling. In the normal state, the band structure realizes a $j = 3/2$ semimetal. Remarkably, the repulsive Hubbard interaction leads to an *attractive* superconducting pairing interaction in the E_g channel, which allows a two-component order parameter, whereas the interaction is repulsive in the trivial A_{1g} channel. The attractive interaction relies on the fact that the E_g pairing avoids the detrimental on-site repulsion. The solution of the BCS gap equation shows that a time-reversal-symmetry-breaking superconducting phase is favored, which displays Bogoliubov Fermi surfaces.

TT 38.2 Fri 9:45 H23

Pairing instabilities of the Yukawa-SYK models with controlled fermion incoherence — •Wonjune Choi[1,2], Omid Tavakol[3], and Yong Baek Kim[3] — [1]Department of Physics, Technical University of Munich, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Department of Physics, University of Toronto, Toronto, Ontario M5S 1A7, Canada

As a solvable platform of the strongly correlated superconductors, we study the pairing instabilities of the Yukawa-Sachdev-Ye-Kitaev (Yukawa-SYK) model, which describes spin-1/2 fermions coupled to bosons by the random, all-to-all Yukawa interactions. In contrast to the previously studied models, the random Yukawa couplings are sampled from a collection of Gaussian ensembles whose variances follow a continuous distribution rather than being fixed to a constant. By tuning the analytic behaviour of the distribution, we control the fermion incoherence to systematically examine various normal states ranging from the Fermi liquid to non-Fermi liquids that are different from the conformal solution of the SYK model with a constant variance. Using the linearised Eliashberg theory, we show that the onset of the unconventional spin-triplet pairing is preferred with the spin-dependent interactions. Although the interactions shorten the lifetime of the fermions in the non-Fermi liquid, the same interactions also dress the bosons to strengthen the tendency to pair the incoherent fermions. As a consequence, the onset temperature of the pairing is enhanced in the non-Fermi liquid compared to the case of the Fermi liquid.

TT 38.3 Fri 10:00 H23

Superconducting pairing from repulsive interactions of fermions in a flat-band system — Iman Mahyaeh[1], •Thomas Köhler[1], Annica M. Black-Schaffer[1], and Adrian Kantian[1,2] — [1]Department of Physics and Astronomy, Uppsala University, Sweden — [2]SUPA, Institute of Photonics and Quantum Sciences, Heriot-Watt University, Edinburgh EH14 4AS, United Kingdom

Many-body quantum systems of fermions with flat bands at the Fermi level are intensely studied for their potential to boost superconductivity by enhancement of the density of states. We use quasiexact numerical methods to show that repulsive interactions between spinless fermions in a model one-dimensional flat band system, the Creutz ladder, lead to a finite pairing energy that increases with repulsion. Pure repulsion however leaves charge-order as the dominant quasi-order over the superconductivity. Adding an additional attractive component to the interaction shifts the balance fully in favor of superconductivity. In this regime we find that the interactions of two flat bands further yields a remarkable enhancement to superconductivity far above and outside the known paradigms for one-dimensional fermions.

TT 38.4 Fri 10:15 H23

Degenerate plaquette physics as key ingredient of high-temperature superconductivity in cuprates — Mikhail Danilov[1], van Loon Erik G. C. P.[2], •Brener Sergey[1,3], Iskakov Sergey[4], Katsnelson Mikhail[5], and Lichtenstein Alexander[1,3] — [1]Institute of Theoretical Physics, University of Hamburg — [2]Department of Physics, Lund University — [3]The Hamburg Centre for Ultrafast Imaging — [4]Department of Physics, University of Michigan — [5]Radboud University, Institute for Molecules and Materials

A major pathway towards understanding complex systems is given by exactly solvable reference systems that contain the essential physics of the system. For the $t - t' - U$ Hubbard model, the four-site plaquette is known to have a point in the $U - \mu$ space where states with electron occupations $N = 2, 3, 4$ per plaquette are degenerate. Such a degenerate point causes strong fluctuations when a lattice of plaquettes is constructed. The next-nearest-neighbour hopping is shown to play a crucial role in the formation of strongly bound electronic bipolarons whose coherence at lower temperature could be the explanation for superconductivity. A complementary approach to the lattice of plaquettes is given by dual fermion perturbation theory starting from a single degenerate plaquette as a reference system. This perturbation theory already contains the relevant short-ranged fluctuations from the beginning via the two-particle correlations of the plaquette. We find that d-wave superconductivity remains a leading instability channel under a reasonably broad range of parameters.

TT 38.5 Fri 10:30 H23

Charge 4e skyrmion superconductivity? — •Gabriel Rein[1,2], Marcin Raczkowski[1], and Fakher F. Assaad[1,2] — [1]Institut für Theoretische Physik und Astrophysik Universität Würzburg, 97074 Würzburg, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany

We consider a dynamically generated quantum spin Hall (QSH) state which has as characteristic that skyrmion excitations of the SO(3) order parameter carry charge $2e$. In Refs. [1,2] a model was defined with a single parameter λ that drives a continuous transition akin to deconfined quantum criticality from a QSH insulator to an s-wave superconductor via the condensation of charge $2e$ skyrmions. Our aim here is to modify this Hamiltonian by adding flavor degrees of freedom N_f, such that the charge of the skyrmion reads $N_f 2e$. In this talk we will map out the phase diagram of the model at $N_f = 2$. Although, to date charge 4e skyrmion superconductivity remains elusive, the phase diagram in the N_f versus λ plane is very rich with additional Kekule ordered phases.

[1] Y. Liu, Z. Wang, T. Sato, M. Hohenadler, C. Wang, W. Guo, and F. F. Assaad, Nat. Commun. 10 (2019) 2658
[2] Z. Wang, Y. Liu, T. Sato, M. Hohenadler, C. Wang, W. Guo, F. F. Assaad, Phys. Rev. Lett. 126 (2021) 205701

TT 38.6 Fri 10:45 H23

Groundstate phase diagrams of variants of the two-leg t-J ladder at low fillings — •Steffen Bollmann[1,2], Alexander Osterkorn[2], Elio König[1], and Salvatore R. Manmana[2] — [1]Max-Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]Institut for Theoretical Physics, Georg-August-University Göttingen, 37077 Göttingen, Germany

We study variants of the two-leg t-J ladder at low fillings using matrix product states (MPS) and perturbative approaches. While the groundstate phase diagram for the usual t-J ladder with spatially isotropic couplings at fillings $n > 0.5$ has been studied in detail, relatively little is known at low fillings. We address the phase diagram at these low fillings and investigate the influence of nearest-neighbor Coulomb interactions V and asymmetries in the spin-exchange $J_z \neq J_x = J_y$ on the size and nature of superconducting phases. For $V = 0$ the superconducting phase is enhanced, and we find a crossover within this phase from s-wave pairing to d-wave pairing when increasing the filling. For $J_z = 0$, the size of the superconducting region is reduced. In this talk, I will present the phase diagrams, discuss the physics, briefly introduce the methods used to classify the different phases, and give an outlook to possible realizations in experiments.

TT 39: Correlated Electrons: Charge Order

Time: Friday 11:15–13:15 Location: H23

TT 39.1 Fri 11:15 H23

Stripe discommensuration and spin dynamics of charge and spin stripe ordered $Pr_{3/2}Sr_{1/2}NiO_4$ — •Avishek Maity[1], Rajesh Dutta[2,3], and Werner Paulus[4] — [1]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, 85747 Garching, Germany — [2]Institut für Kristallographie, RWTH Aachen Universität, 52066 Aachen, Germany — [3]Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ), 85747 Garching, Germany — [4]Institut Charles Gerhardt Montpellier, Université de Montpellier, 34095 Montpellier, France

Magnetic excitations in the charge and spin stripe ordered phases of La-based 214-nickelates have been vigorously explored using inelastic neutron scattering (INS) studies. In view of so far reported two-dimensional antiferromagnetic nature, out-of-plane interaction is not generally expected in 214-nickelates. Here we will present our results on the magnetic excitations of $Pr_{3/2}Sr_{1/2}NiO_4$, with stripe incommensurability $\epsilon = 0.4$, showing a very compelling evidence for the presence of a sizable out-of-plane interaction ($J_\perp \sim 2.2$ meV) manifesting a symmetrical outward shift of the spin wave dispersion from the antiferromagnetic zone center. Our linear spin wave calculation using an unconventional three-dimensional model of discommensurated spin stripe (DCSS) unit for $\epsilon = 0.4$ could explicitly show such outward shift results from the overlap of a mode originating exclusively from the out-of-plane interaction. Our study suggests that a careful consideration of the out-of-plane interaction is necessary in the stripe discommensurated 214-nickelates.

[1] A. Maity et al., PRL 124, 147202 (2020).

TT 39.2 Fri 11:30 H23

Quantum oscillations in the Kagome superconductor CsV_3Sb_5 — •Anmol Shukla[1], Liran Wang[1], Frédéric Hardy[1], Amir-Abbas Haghighirad[1], Mingquan He[2], Wei Xia[3], Yanfeng Guo[3], and Christoph Meingast[1] — [1]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [2]Low Temperature Physics Lab, College of Physics & Center of Quantum Materials and Devices, Chongqing University, Chongqing 401331, China — [3]School of Physical Science and Technology, ShanghaiTech University, Shanghai 201210, China

The recently discovered layered Kagome metals AV_3Sb_5 (A = K, Rb, Cs) exhibit a unique combination of nontrivial band topology, competing for the charge- and superconducting orders with clear signatures of electron correlations. Using magnetization, resistivity, thermal expansion, magnetostriction and heat capacity, we have investigated the normal- and superconducting-state properties of single crystals of the kagome superconductor CsV_3Sb_5. The magnetization and magnetostriction data show clear signatures of quantum oscillations with at least two distinct frequencies. These are much less evident in the heat capacity. Combining the results from these thermodynamic probes and transport measurement, we discuss the nature of the Fermi surface and the interplay between the charge order and superconductivity.

TT 39.3 Fri 11:45 H23

Statistical learning of engineered topological phases in the Kagome superlattice of AV_3Sb_5 — Thomas Mertz, •Paul Wunderlich, Shinibali Bhattacharyya, Francesco Ferrari, and Roser Valentí — Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt am Main, Germany

Recently, the kagome metals AV_3Sb_5 (A = K,Rb,Cs) have gained intense research interest, as they display a wide spectrum of exotic topological properties, in addition to superconductivity, charge, orbital momentum and spin density waves. Motivated by a plethora of experimental evidence for unconventional charge orders in the enlarged (2×2) unit-cell of the vanadium based kagome metals, we investigate the type of topological phases that can manifest within the electronic parameter space of such kagome superlattices. Unlike conventional theoretical approaches, we employ a recently introduced statistical method capable of constructing topological models for any generic lattice, in an unbiased way without prior knowledge of its phase diagram. By extracting physically meaningful information from large datasets of randomized hopping parameters for the kagome superlattice, we find possible real-space manifestations of charge and bond modulations and associated flux patterns for different topological classes. Our results agree with contemporary theoretical propositions and experimental observations for the AV_3Sb_5 family. Simultaneously, we predict new higher-order topological phases that may be realized by appropriately manipulating the currently known systems.

TT 39.4 Fri 12:00 H23

High-pressure IR investigations unveil modifications in the electronic structure of the superconducting Kagome metal CsV_3Sb_5 — •Maxim Wenzel[1], Yuk T. Chan[1], Brenden R. Ortiz[2,3], Stephen D. Wilson[3], Martin Dressel[1], Alexander A. Tsirlin[4], and Ece Uykur[1] — [1]1. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart, Germany — [2]California Nanosystems Institute, University of California Santa Barbara, Santa Barbara, CA, 93106, United States — [3]Materials Department, University of California Santa Barbara, Santa Barbara, CA, 93106, United States — [4]Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg, 86159 Augsburg, Germany

The non-magnetic Kagome metal series AV_3Sb_5 with A = K, Cs, or Rb is known for the coexistence of charge-density-wave and superconducting orders at low temperatures. Previously, the tunability of both orders has been investigated extensively via high-pressure transport studies; however, the pressure-induced modifications of the electronic band structure, especially the position of the saddle points, remain the subject of current research. While theoretical studies present conflicting suggestions regarding the pressure effects on the band structure, it has been shown that the interband optical transitions are highly sensitive to the position of the saddle points and hence, can probe them experimentally. Therefore, we performed high-pressure infrared studies on the model compound CsV_3Sb_5 at room temperature to trace the behavior of the interband optical transitions up to 17 GPa.

TT 39.5 Fri 12:15 H23

Charge-density waves in Kagome-lattice extended Hubbard models at the van Hove filling — •Francesco Ferrari[1], Federico Becca[2], and Roser Valentí[1] — [1]Goethe University, Frankfurt am Main, Germany — [2]University of Trieste, Trieste, Italy

The Hubbard model on the kagome lattice is presently often considered as a minimal model to describe the rich low-temperature behavior of AV_3Sb_5 compounds (with A=K, Rb, Cs), including charge-density waves (CDWs), superconductivity, and possibly broken time-reversal symmetry. We investigate, via variational Jastrow-Slater wave functions, the properties of its ground state when both onsite U and nearest-neighbor V Coulomb repulsions are considered at the van Hove filling. Our calculations reveal the presence of different interaction-driven CDWs and, contrary to previous renormalization-group studies, the absence of ferromagnetism and charge- or spin-bond order. No signatures of chiral phases are detected. Remarkably, the CDWs triggered by the nearest-neighbor repulsion possess charge isproportionations that are not compatible with the ones observed in AV_3Sb_5. As an alternative mechanism to stabilize charge-bond order, we consider the electron-phonon interaction, modeled by coupling the hopping amplitudes to quantum phonons, as in the Su-Schrieffer-Heeger model. Our results show the instability towards a tri-hexagonal distortion with 2x2 periodicity, in a closer agreement with experimental findings.

TT 39.6 Fri 12:30 H23

Chalcogenic orbital density waves in the weak- and strong-coupling limit — •Adam Klosinski[1], Andrzej M. Oles[2,3], Clio Efthimia Agrapidis[1], Jasper van Wezel[4], and Krzysztof Wohlfeld[1] — [1]University of Warsaw, Warsaw, Poland — [2]Jagiellonian University, Krakow, Poland — [3]Max Planck Institute for Solid State Research, Stuttgart, Germany — [4]University of Amsterdam, Amsterdam, The Netherlands

Stimulated by recent works highlighting the indispensable role of Coulomb interactions in the formation of helical chains and chiral electronic order in the elemental chalcogens, we explore the p-orbital Hubbard model on a one-dimensional helical chain. By solving it in the Hartree approximation we find a stable ground state with a period-3 orbital density wave. We establish that the precise form of the emerging order strongly depends on the Hubbard interaction strength. In the strong-coupling limit, the Coulomb interactions support an orbital density wave that is qualitatively different from that in the weak-coupling regime. We identify the phase transition separating these two orbital ordered phases and show that realistic values for the interorbital Coulomb repulsion in elemental chalcogens place them in the weak-coupling phase, in agreement with observations of the order in the elemental chalcogens.

TT 39.7 Fri 12:45 H23

Understanding the transition from metal to Hund's insulator in $CaFeO_3$ — •Maximilian Merkel and Claude Ederer — Materials Theory Group, ETH Zürich, Switzerland

Materials where strong correlations are caused by the Hund's interaction have recently attracted a lot of attention. In some cases, a dominant Hund's interaction can even lead to the emergence of a charge-disproportionated insulating (CDI) or "Hund's insulating" state. One example is the perovskite transition-metal oxide $CaFeO_3$ (CFO), which exhibits a transition from metal to Hund's insulator around room temperature. This transition couples to a structural distortion that creates alternating large and small FeO_6 octahedra, leading to two inequivalent Fe sites with nominal Fe^{5+} and Fe^{3+} charge states. We study CFO using density functional theory (DFT) and dynamical mean-field theory (DMFT). To characterize the CDI state, we first apply DMFT to a five-orbital Hubbard model applicable to CFO and demonstrate the emergence of the CDI phase here [1]. We then investigate the energetics of the transition using fully self-consistent DFT+DMFT calculations. We discuss the ligand-hole character of the charge disproportionation due to the zero or even negative charge-transfer energy. Our calculations show that both structural and electronic properties of the CDI state are well described within DFT+DMFT but also that the subtle interplay of several effects represents a big challenge for any quantitative, predictive theory.

[1] M. E. Merkel and C. Ederer, Phys. Rev. B 104, 165135 (2021)

TT 39.8 Fri 13:00 H23

Reinvestigating the metallic region of the half-filled Hubbard Holstein model — Sam Mardazad[1], Martin Grundner[1], Ulrich Schollwöck[1], Adrian Kantian[2], Thomas Köhler[3], and •Sebastian Paeckel[1] — [1]Department of Physics, Arnold Sommerfeld Center of Theoretical Physics, University of Munich, Germany — [2]Institute of Photonics and Quantum Sciences, Heriot-Watt University, Edinburgh, UK — [3]Department of Physics and Astronomy, Uppsala University, Sweden

The one-dimensional Hubbard-Holstein model is the paradigmatic system to study the interplay between strongly correlated electrons and dispersionless lattice vibrations. Particularly, the intermediate regime of competing interactions has been heavily debated and only with the advent of powerful numerical techniques such as density-matrix renormalization group (DMRG) or advanced quantum Monte Carlo (QMC), the realization of an intermediate metallic phase has been established. However, these early studies are characterized by significant truncations of the phononic Hilbert spaces. Here, we exploit recent advances in the efficient representation of large local Hilbert spaces to re-examine the phase diagram by large-scale DMRG calculations, focussing on the regime of competing, strong interactions. This allows us to systematically study the complex competition between correlations, overcoming previous limitations.