Abstract Booklet

Session: Adatom surface design (I)

Roland Wiesendanger: *Bottom-Up Design of Topological Superconductors*

Sander Otte: *Studying coherent quantum dynamics of atomic spin chains*

Jelena Klinovaja: *Superconducting diode effect due to magnetochiral anisotropy in topological insulator and Rashba nanowires*

The critical current of a superconductor can depend on the direction of current flow due to magnetochiral anisotropy when both inversion and time-reversal symmetry are broken, an effect known as the superconducting (SC) diode effect. Here, we consider one-dimensional (1D) systems in which superconductivity is induced via the proximity effect. In both topological insulator and Rashba nanowires, the SC diode effect due to a magnetic field applied along the spin-polarization axis and perpendicular to the nanowire provides a measure of inversion symmetry breaking in the presence of a superconductor. Furthermore, a strong dependence of the SC diode effect on an additional component of magnetic field applied parallel to the nanowire as well as on the position of the chemical potential can be used to detect that a device is in the region of parameter space where the phase transition to topological superconductivity is expected to arise.

[1] Henry F. Legg, Daniel Loss, and Jelena Klinovaja, arXiv:2205.12939
[2] Henry F. Legg, Matthias Rößler, Felix Münning, Dingxun Fan, Oliver Breunig, Andrea Bliesener, Gertjan Lippertz, Anjana Uday, A. A. Taskin, Daniel Loss, Jelena Klinovaja, and Yoichi Ando, Nature Nanotechnology (2022)
[3]Henry F. Legg, Daniel Loss, and Jelena Klinovaja, Phys. Rev. B 105, 155413 (2022)
[4] Henry F. Legg, Daniel Loss, and Jelena Klinovaja, Phys. Rev. B 104, 165405 (2021)

Freek Massee: *Tunnelling process into sub-gap states in NbSe2 revealed by atomic scale shot-noise*

Isolated electronic states generated by single atom impurities, such as acceptor and donor states in semiconductors and in-gap states in superconductors, are ideal building blocks for bottom-up constructed devices. Particularly chains and islands of magnetic impurities in superconductors have attracted considerable attention recently as they may host Majorana fermions. One of the challenges in this endeavour is to understand the intrinsic lifetime of the localised states, also known as Yu-Shiba-Rusinov (YSR) states, which is expected to be limited by the inelastic coupling with the continuum. Here I will present how we used shot-noise scanning tunnelling microscopy combined with theoretical modelling to gain a deeper insight into YSR states in superconducting NbSe2 [1]. The current noise reveals the coexistence of both coherent and incoherent tunnelling processes into the in-gap states, and enables us to extract their intrinsic lifetime which is usually inaccessible to regular spectroscopy.

[1] U. Thupakula et al., arXiv:2111.04749 (2021)

Levente Rózsa: *Tailoring Yu-Shiba-Rusinov states on the surface of elemental superconductors*

Magnetic impurities in conventional superconductors locally break Cooper pairs, leading to the emergence of Yu-Shiba-Rusinov (YSR) bound states. Chains of YSR impurities have been theoretically predicted to give rise to Majorana bound states, which hold promises for realizing topological quantum computers. A fundamental understanding of the formation of YSR states in small atomic clusters is essential for revealing the topological properties of the YSR band structure. The accurate theoretical modelling of YSR states represents a considerable challenge, since it requires a simultaneous description of the electronic structure, the magnetic ordering of the impurities and superconductivity on significantly different energy scales.
Here, first-principles simulations are combined with tight-binding model calculations to determine the influence of the electronic and magnetic structure on the spatial profile of individual YSR states and on the interactions between the states. It is shown how the shape of the Fermi surface leads to a long-ranged anisotropic extension of YSR states in the vicinity of magnetic impurities [1]. It is explained how the spin-orbit coupling influences the hybridization of YSR bound states of dimers with ferromagnetic and antiferromagnetic spin alignments [2]. The calculations are extended to atomic chains [3] with various magnetic configurations, where the topology of the YSR band structure is analyzed. The theoretical concepts are illustrated by experimental realizations in specific materials.

[1] H. Kim, L. Rózsa, D. Schreyer, E. Simon, and R. Wiesendanger, Nat. Commun. 11, 4573 (2020).
[2] P. Beck, L. Schneider, L. Rózsa, K. Palotás, A. Lászlóffy, L. Szunyogh, J. Wiebe, and R. Wiesendanger, Nat. Commun. 12, 2040 (2021).
[3] L. Schneider, P. Beck, J. Neuhaus-Steinmetz, L. Rózsa, T. Posske, J. Wiebe, and R. Wiesendanger, Nat. Nanotechnol. 17, 384 (2022).

Session: Classical and quantum spins (I)

Rembert Duine: *Antimagnonics*

In this talks I will discuss how spin transfer torques may be used to dynamically stabilize magnetic configurations at an energy maximum. The collective excitations in such configurations are negative-energy excitations that are most conveniently described in terms of antimagnons. Coupling ordinary magnons to these antimagnons paves the way for schemes for magnon amplification and lasing that will highlighted.

Toeno van der Sar: *Magnetic imaging of spin-wave dynamics using electron spins in diamond*

Magnetic imaging based on the electron spin of the nitrogen-vacancy (NV) center in diamond is well suited for probing condensed matter systems with nanoscale resolution [1]. In this talk I will introduce NV magnetometry as a tool for imaging spin waves – the wave-like spin excitations of magnetic materials. Using the NV sensitivity to microwave magnetic fields, we can map both coherent spin waves [2] and incoherent magnon gases [3] to provide insight into their interaction and damping mechanisms. A unique aspect of the technique is that the imaging is magnetic; This enables studies of spin waves underneath opaque materials (such as electrodes on a chip) and of interactions in hybrid metal – spin-wave systems [4]. By using an NV in a scanning diamond tip we gain access to spin waves at the nanoscale and can use the nanoscale control of the NV-sample distance as a filter to selectively image a target spin wave within a frequency-degenerate ensemble [5]. I will also show how spin-wave mixing in hybrid magnet-diamond chips enable the detection of microwave fields that are otherwise out of reach of

NV magnetometry [6]. These results form a basis for developing NV magnetometry into a tool for characterizing spin-wave devices and expand the sensing capabilities of NV centers.

[1] Casola, F., Van Der Sar, T. & Yacoby, A. Probing condensed matter physics with magnetometry based on nitrogen-vacancy centres in diamond. Nat. Rev. Mater. 3, 17088 (2018).
[2] Bertelli, I. et al. Magnetic resonance imaging of spin-wave transport and interference in a magnetic insulator. Sci. Adv. 6, eabd3556 (2020).
[3] Simon, B. G. et al. Directional Excitation of a High-Density Magnon Gas Using Coherently Driven Spin Waves. Nano Lett. 21, 8213–8219 (2021).
[4] Bertelli, I. et al. Imaging Spin-Wave Damping Underneath Metals Using Electron Spins in Diamond. Adv. Quantum Technol. 4, 2100094 (2021).
[5] Simon, B. G. et al. Filtering and imaging of frequency-degenerate spin waves using nanopositioning of a single-spin sensor. Arxiv:2207.02798 (2022).
[6] Carmiggelt, J. J. et al. Broadband microwave detection using electron spins in a hybrid diamond-magnet sensor chip. Arxiv:2206.07013 (2022).

Yaroslav Tserkovnyak: *Novel transport and probes of quantum materials based on topological spin textures*
I will discuss new strategies to interrogate and exploit collective dynamics of magnetic systems by driving their topological flavors. Two key ingredients will be at play: (1) identifying topologically conserved neutral quantities that can be controlled by electrical means and (2) tailoring the symmetries of the biased system to enable their injection and detection. After formulating the general ideas, I will discuss several informative examples and comment on potential applications, such as nonchemical energy storage, innate neuromorphic functionalities, and quantum communication.

Gerrit Bauer: *Magnonics versus Ferronics*

Ferromagnets and ferroelectrics are phases of condensed matter in which magnetic and electric dipoles align spontaneously below a Curie temperature. “Magnons” (“ferrons”) are the elementary excitations of the magnetic (electric) order that carry spin (electric) polarization, momentum, and energy. I will present a short overview and selected theoretical results in magnonics and ferronics and compare with available experiments.

[1] G.E.W. Bauer, R. Iguchi, and K. Uchida, “Theory of Transport in Ferroelectric Capacitors”, Phys. Rev. Lett. 126, 187603 (1-4) (2021).
[2] P. Tang, R. Iguchi, K. Uchida and G.E.W. Bauer, “Thermoelectric Polarization Transport in Ferroelectric Ballistic Point Contacts”, Phys. Rev. Lett. 128, 047601 (1-6) (2022).
[3] M. Elyasi, E. Saitoh, and G.E.W. Bauer, “Theory of the Magnon Parametron”, Phys. Rev. B 105, 054403 (2022).
[4] P. Tang, R. Iguchi, K. Uchida, and G.E.W. Bauer, “Excitations of the ferroelectric order”, Phys. Rev. B 106,L081105 (2022).
[5] T. Yu and G.E.W. Bauer, Efficient Gating of Magnons by Proximity Superconductors, Phys. Rev. Lett. 129, 117201 (2022).
[6] M. Kounalakis, G.E.W. Bauer, Y. M. Blanter, Analog quantum control of magnonic cat states on-a-chip by a superconducting qubit, Phys. Rev. Lett. 129, 037205 (1-7) (2022),
[7] X-Y. Wei, O. Alves Santos, C.H. Sumba Lusero, G. E. W. Bauer, J. Ben Youssef, and B. J. van Wees, Giant magnon spin conductivity approaching the two-dimensional transport regime in ultrathin yttrium iron garnetfilms, Nat. Mater. 10.1038/s41563-022-01369-0 (2022).

[8] P. Tang, K. Uchida, and G.E.W. Bauer, Nonlocal Drag Thermoelectricity Generated by Ferroelectric Heterostructures, arXiv:2207.00240 .
[9] P. Tang and G.E.W. Bauer, The sliding phase transition in ferroelectric van der Waals bilayers, arXiv:2208.00442.

Session: Topological physics (I)

Joseph Heremans: *The Bi(1-x)Sb(x) topological insulator/Weyl semimetal system: chiral anomalies, anomalous Nernst effect, giant thermal Hall effect*

Bi(1-x)Sb(x) alloys are solid solutions. For x < 4 at.%, they are trivial semimetals. In the absence of a magnetic field, they have a rich phase diagram with indirect-gap and direct-gap topological insulators. These alloys can be prepared with exquisite purity, carrier densities as low as 6E14 cm^-3 and mobilities up to 3,000,000 cm2/V.s at 10K. In the presence of a magnetic field along the trigonal direction, they become Weyl semimetals. The thermal and electrical chiral anomalies in this phase are very intense and were reported previously (Vu et al. Nat. Mater. 20,1525–1531 (2021)] on undoped samples with x=11% and x=15%. Here we extend the data to 2K, and cover the entire range of compositions where the samples are TI's, as well as samples doped deliberately n-type and p-type. We observe a surprising enhancement of the thermal chiral anomaly below 10K. We further observe a very large thermal Hall effect, possibly with a contribution of the surface states in the Weyl phase. Finally, the Nernst thermopower and conductivity are amongst the largest ever measured on any material.

Timo Hyart: *Topological excitations in non-Hermitian chiral-symmetric systems*

In this talk, I will discuss topological effects in one-dimensional chiral-symmetric non-Hermitian systems. By mapping the one-dimensional non-Hermitian problem into an effective two-dimensional Hermitian problem, I will show that the topology of these systems is described by a Chern number which determines the number of topological end modes [1]. I will introduce a minimal model Hamiltonian supporting topologically nontrivial phases in this symmetry class, derive its topological phase diagram and calculate the end states originating from the Chern number. Then I will discuss the possible realization of the topologically nontrivial non-Hermitian phases in polariton systems [2] and strongly interacting systems realized in quantum dot arrays [3]. Finally, I will show that this type of non-Hermitian topology leads to interesting quantum effects in a chain of transmons coupled to quantum circuit refrigerators [4].

[1] W. Brzezicki and T. Hyart, Hidden Chern number in one-dimensional non-Hermitian chiral-symmetric systems, Phys. Rev. B 100, 161105(R) (2019).
[2] P. Comaron, V. Shahnazaryan, W. Brzezicki, T. Hyart, M. Matuszewski, Non-Hermitian Topological End-Mode Lasing in Polariton Systems, Phys. Rev. Research 2, 022051(R) (2020).
[3] T. Hyart and J. L. Lado, Non-Hermitian many-body topological excitations in quantum dots, Phys. Rev. Research 4, L012006 (2022).
[4] W. Brzezicki, M. Silveri, M. Plodzien, F. Massel and T. Hyart, in preparation (2022).

Stefan Kühn: *Onset of topological protection in finite-size quantum spin helices*

We explore the stability of quantum spin helices in the quantum XXZ model and identify previously overlooked phantom helices. To quantify their stability, we perform numerical simulations, time-dependent perturbation theory, and a Lindblad approach. Our results reveal that phantom helices and a more general class of super-spincurrent-maximizing helices typically reach the stability of the ground state and partially even exceed it. This stability originates from the finite-size onset of topological sectors, strongly suppressing transitions between states of different helicity while excitations within a helicity sector are still present. Thus, topological protection is identified as a cause of time-scale separation and linked to weak ergodicity breaking.

Alexander Mook: *Interacting topological magnons*

Topological magnets support magnetic excitations with a topologically nontrivial spectrum. As a result, they exhibit chiral edge states akin to those known from the quantum Hall effect. These edge states are envisioned to facilitate backscattering-free information channels for magnetic signals [1]. Since spin excitations do not carry charge, they do not suffer from Joule heating and facilitate ultra-low energy computation. However, in contrast to electrons, there is no conservation law for spin excitations. This gives rise to particle number-nonconserving many-body interactions the influence of which on quasiparticle topology is an open issue of fundamental interest in the field of topological quantum materials. Herein, I concentrate on magnons - the elementary spin excitations of ferromagnets - and discuss several aspects of many-body effects caused by particle-number nonconservation. These include (i) quantum damping due to spontaneous quasiparticle decay [2], (ii) interaction-stabilized topological gaps in the single-particle spectrum [3], and (iii) a topological hybridization of states belonging to different particle number sectors [4]. These effects highlight the fundamental difference between electronic and magnonic topology.

[1] Alexander Mook, Sebastián A. Díaz, Jelena Klinovaja, and Daniel Loss, "Chiral Hinge Magnons in Second-Order Topological Magnon Insulators," Phys. Rev. B 104, 024406 (2021)
[2] Alexander Mook, Jelena Klinovaja, and Daniel Loss, "Quantum damping of skyrmion crystal eigenmodes due to spontaneous quasiparticle decay," Phys. Rev. Research 2, 033491 (2020)
[3] Alexander Mook, Kirill Plekhanov, Jelena Klinovaja, and Daniel Loss, "Interaction-Stabilized Topological Magnon Insulator in Ferromagnets," Phys. Rev. X 11, 021061 (2021)
[4] Alexander Mook, Rhea Hoyer, Jelena Klinovaja, and Daniel Loss, "Topological Hybridization of Magnons and Magnon Bound Pairs," arXiv:2203.12374 (2022)

Andreas Haller: *Quantum Skyrmion Lattices in Heisenberg Ferromagnets*

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 invidual 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.

Session: Adatom surface design (II)

Pascal Simon: *New insights from electronic transport in superconducting bound-states*

Javad Shabani: *Towards Topological Superconductivity in Epitaxial Superconductor-Semiconductor Systems*

A central goal in quantum condensed matter physics is to understand and control the order parameter characterizing the collective state of electrons in quantum heterostructures. For example, new physical behaviors can emerge that are absent in the isolated constituent materials. With regards to superconductivity this has opened new area of investigation in the search for topological superconductivity. This type of superconductivity is expected to host exotic quasi-particle excitations including Majorana bound states which hold promise for fault-tolerant quantum computing. In this talk, we first discuss the important role of epitaxial superconductor-semiconductor hybrid systems as an enabling materials platform. We present unprecedented values of transparency and induced gap that could allow us to reach into previously unexplored parameter regimes. In wide Josephson junctions exposed to magnetic field, we observe a minimum of critical current accompanied with a phase jump in the superconducting phase. We discuss this observation as a signature of a transition between trivial and topological superconductivity. These findings reveal a versatile two-dimensional platform to explore mesoscopic and topological superconductivity for quantum information science.

Falko Pientka: *Signatures of Majorana states in magnetic adatom chains*

Signatures of Majorana states have been found in STM experiments probing magnetic adatom chains on the surface of a superconductor. In this talk, I will discuss the intriguing physics of the proximity effect in this system, which gives rise to a series of unexpected phenomena such as strongly localized Majorana states and an unconventional topological phase with long-range couplings. I will also address experimental challenges of STM experiments on superconductors and show how an improved understanding of the relevant tunneling processes can be used to determine quasiparticle dynamics of superconducting bound states.

Rubén Seoane Souto: *Semi-Super-Ferro: A new platform for unconventional superconductivity*

Topological superconductors are attractive platforms for fault-tolerant quantum devices. In 1-dimension, they host well-separated Majorana quasiparticles at their ends, which can encode information in a protected way. The first proposed platforms for topological superconductivity require relatively large magnetic fields, setting constraints on the device's geometries [1]. Ferromagnetic insulating materials (FIM), such as EuS or EuO, can help overcome these limitations, eliminating the requirement of external magnetic fields. Recently, robust zero-energy states have been reported in the semiconductor-superconductor-ferromagnetic insulator platform [2], consistent with the presence of Majorana bound states. In this presentation, I will discuss how FIMs can help inducing topological properties in the device. I will discuss recent Coulomb blockade measurements of semiconducting InAs nanowires, partially covered with Al and EuS shells and tunnel-coupled to normal leads. By comparing experimental results to a theoretical model, we associate inelastic cotunneling features in even-odd periodic Coulomb-blockade spectra with spin-polarized subgap Andreev levels. Our study suggests spin-splitting exceeding the induced superconducting gap at zero magnetic field [3]. I will also discuss the transport properties of spin-polarized Andreev bound states in Josephson junctions, analyzing the role of magnetic domains [4].

[1] R. M. Lutchyn, E. P. A. M. Bakkers, L. P. Kouwenhoven, P. Krogstrup, C. M. Marcus, and Y. Oreg, Nat. Rev. Mat. 3, 52 (2018)

[2] S. Vaitiekėnas, Y. Liu, P. Krogstrup, and C. M. Marcus, Nat. Phys. 17, 43 (2021)
[3] S. Vaitiekėnas, R. Seoane Souto, Y. Liu, P. Krogstrup, K. Flensberg, M. Leijnse, and C. M. Marcus, Phys. Rev. B L041304 (2022)
[4] D. Razmadze, R. Seoane Souto, L. Galletti, A. Maiani, Y. Liu, P. Krogstrup, C. Schrade, A. Gyenis, C. M. Marcus, and S. Vaitiekėnas, arXiv:2204.03202 (2022)

Archana Mishra: *Quantum computing with Yu-Shiba-Rusinov states in superconductors*

Magnetic impurities in s-wave superconductor lead to spin polarized Yu-Shiba-Rusinov (YSR) states and is a viable setup to realize Majorana zero modes, a promising candidate for topological quantum computers. However, this is a distant goal since no quantum coherent degrees of freedom have yet been identified in these systems. To fill this gap we propose an effective two-level system, a YSR qubit, stemming from two nearby impurities on a superconductor. Using a time-dependent wave-function approach, we derive an effective Hamiltonian describing the YSR qubit evolution and propose alternative ways for the manipulation and read out of the qubit: (i) through the precession of the magnetic impurities and (ii) with supercurrents originating from a phase-bias superconducting tips. Finally, we examine effect of the spin noises on the coherence properties of the YSR qubit and demonstrate its robustness over a wide range of experimentally relevant parameters. The YSR qubit could facilitate the implementation of a universal set of quantum gates in hybrid systems where they are coupled to topological Majorana qubits.

Kristján Óttar Klausen: *Majorana Zero Modes in Core-shell Nanowires*

The hosting of multiple Majorana Zero Modes in a core-shell nanowire system with proximity-induced superconductivity is described in light of recently fabricated heterostructure geometries. Andreev reflection and the Little-Parks effect within such a system are discussed.

Session: Topological physics (II)

Jan Carl Budich: *Non-Hermitian Topology from Electronic Correlations*

In a variety of physical scenarios ranging from classical meta-materials to correlated quantum many-body systems, non-Hermitian (NH) Hamiltonians have proven to be a powerful and conceptually simple tool for effectively describing dissipation. Recently, investigating the topological properties of such NH systems has become a broad frontier of research. In this talk, I will discuss how NH topological features such as stable exceptional degeneracies and a remarkable spectral sensitivity with respect to boundary conditions can emerge in the quasi-particle description of correlated electron systems that are globally described by a Hermitian Hamiltonian. In particular, I will demonstrate how magnetic fluctuations at the onset of ferromagnetism may promote the symmetry-protected nodal surface states of a topological insulator to a NH Weyl phase that is robust against generic perturbations.

Erwann Bocquillon: *Microwave transport in HgTe topological insulators*

Research on helical insulator edges states in 2D topological insulators is motivated by exotic fundamental physics, robust topological quantum computation and novel spinorbitronics. However, topological transport is often visible only on short distances. On larger distances, microwave transport offers powerful tools to investigate the origin of this fragility, or to dynamically enhance topological signatures by exploiting the high mobility of edge states with respect to bulk carriers.

In this talk, we report on microwave capacitance spectroscopy in HgTe 2D topological insulators [1]. It highlights the response of the edges which host very mobile carriers, while bulk carriers are drastically slowed down in the gap. The edges have a higher density of states than expected, but charge relaxation occurs on short timescales, which suggest that edge states can be selectively addressed on timescales over which bulk carriers are frozen. We also propose edge resonator geometries to characterize Coulomb interaction by via high-frequency measurements [2], which remains difficult to quantify despite important consequences on the two-particle scattering in topological edge states.

[1] M. Dartiailh et al., Phys. Rev. Lett. 124, 076802 (2020).
[2] A. Gourmelon et al., Phys. Rev. Res. 2, 043383 (2020).

Niccolo Traverso Ziani: *Quantum spin hall constrictions*

The ability to manipulate the distance between the topological edge states of two-dimensional topological insulators is opening new scenarios in view of the realization of topological bound states and anomalous Josephson effect. Moreover, anomalous transport properties in the absence of superconductivity have been detected, although not completely understood. Such developments will be the focus of the talk.

Wolfgang Belzig: *Higher-dimensional topology and fractional states of matter in superconducting systems*

Many robust physical phenomena in quantum physics are based on topological invariants, which are intriguing geometrical properties of quantum states. A prime example is the 2D quantum Hall effect with its quantized Hall conductance by the respective 2D topology as shown by Thouless. Interactions
can dramatically change the picture and cause fractional quantisation that again can be traced to a topological origin. More intriguingly, one can envision higher dimensional topology in more than three dimensions. This was recently beautifully illustrated experimentally in the form of the 4D quantum Hall effect. We propose superconducting nanosystems as a promising platform for realising higher-dimensional topological phenomena and fractional charge transport. We do this by proposing three systems that make use of the recent observation that multi-terminal superconducting structure with N controlled phase differences constitute an N-dimensional synthetic space and enable a realisation of higher-dimensional topologies. We show the following cases
A. An Andreev dot system with a non-trivial second Chern number and a non-Abelian Berry phase.
B. A superconducting realisation of a tensor monopole.
C. A Josephson junction circuit working as fractional Thouless pump for Cooper pairs.
All systems can be realised with present days technology in superconducting nanoelectronics and pave the way to observe higher dimensional topology in superconducting system.

[1] H. Weisbrich, R. L. Klees, G. Rastelli, and W. Belzig, PRX Quantum 2, (2021).
[2] H. Weisbrich, M. Bestler, and W. Belzig, Quantum 5, 601 (2021).

Alexander Lau: *Three-dimensional flat bands in nodal-line semimetals*

Sparked by the discovery of unconventional superconductivity in twisted bilayer graphene, the study of flat-band physics has become a driving force in the search and realization of new phases of matter. In flat-band systems, 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. Going beyond this paradigm, we here 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. Moreover, we identify rhombohedral graphite and CaAgP as promising material candidates to realize our proposal. Finally, we give a brief outlook on our ongoing studies on three-dimensional flat bands.

Session: Classical and quantum spins (II)

Gregory Fiete: *Dynamical tuning and excitations of spin systems*

In this talk I will describe recent work on strategies to dynamically tune spin systems using appropriately chosen laser drives. In addition, I will also describe work on the excitations of spin systems--magnons or otherwise--and how they may possess topological properties or other unusual aspects. I will focus on the role of the spin-lattice interactions on these features, and also discuss heat transport by magnetic excitations.

Xiaoqin Elaine Li: *Magnons in topological materials*

Topological magnons are newly identified bosonic excitations in crystalline magnetic insulators. As bosons, magnon number is not conserved in contrast to electrons. Thus, the consequences of magnon-magnon interactions are anticipated to be drastically different from that of their electronic counterpart. Magnon-magnon interaction in non-Bravais honeycomb lattices is predicted to renormalize the bare magnon bands and lead to a strong momentum-dependent magnon lifetime. To test these predictions, we study an antiferromagnet insulator CoTiO3, which consists of two-dimensional honeycomb lattices vertically stacked in an ABC sequence and has been shown by recent neutron scattering experiments to host topological magnon bands. We probe large-momentum (i.e., short-wavelength) exchange magnons using Raman scattering experiments via two-magnon scattering processes. We find magnons at the Brillouin zone boundary exhibit significantly narrower linewidths (i.e. longer lifetimes) than those at the zone center in CTO. These observations may support predictions that magnon-magnon interaction is not detrimental to magnon lifetimes in topological bands. Our work suggests that topological magnons in the THz frequency range offer exciting opportunities for high-speed and low-loss spintronic devices. I will also briefly discuss magnons and magnetic fluctuations in atomically thin MnBi2Te4 [1].

[1] “Magnons and magnetic fluctuations in atomically thin MnBi2Te4”, David Lujan, Jeongheon Choe, et. al., Nature Communications 13, 2527, 2022.

Shu Zhang: *Emergence of limit cycle in Lindbladian spin dynamics*

Dissipative quantum dynamics in various physical systems is often described by the Lindblad master equations. Since a generic Markovian dissipation leads to decoherence exponential in time, it is not clear whether persistent limit-cycles oscillations, a common and iconic feature in classical dynamics, can emerge out of this picture. Here, we construct a Lindbladian description for the spin dynamics in the presence of both pumping and damping, which, in the large spin limit, is consistent with the semiclassical Landau-Lifshitz-Gilbert-Slonczewski equation widely used in the study of magnetic dynamics. We are able to identify the fingerprints of the emergence of a limit cycle and its onset at the bifurcation point in the Liouvillian spectra. Our work addresses how coherent limit-cycle oscillations and algebraic decay can emerge in a quantum system governed by a Markovian master equation, and provides a nice connection between the study of semiclassical magnetic dynamics and the open quantum spin systems.

Branislav Nikolic: *What is quantum spin torque: Spintronics meets nonequilibrium strongly correlated and long-range entangled quantum matter*

The "standard model" of magnetization dynamics driven by current via conventional (Slonczewski-Berger) spin-transfer (STT) torque is based on [1] single-particle quantum transport treatment of flowing electrons and classical treatment of localized spins within a magnetic material via the Landau-Lifshitz-Gilbert equation. In the "standard model", the transfer of spin angular momentum between flowing electronic spins and localized spins occurs only if they are
noncollinear. However, recent experiments [2] at low temperatures 1 K suggest that fully quantum nonequilibrium many-body framework is required to describe situations where conventional STT is apparently zero, such as collinear but antiparallel electron and localized spins [3], or localized spins whose expectation value is zero [4] in equilibrium due to entanglement as in the case of quantum antiferromagnets, Mott insulators and quantum spin liquids. To solve this long-standing problems, we have recently [3] adapted time-dependent density matrix renormalization (tDMRG) algorithms for "quantum STT," by which we term
any situation where localized spins must be treated quantum-mechanically with their individual expectation values calculated only at the end. This reveals how quantum STT can generate highly entangled nonequilibrium many-body state of all flowing and localized spins with mutual information between localized spins at the FM edges remaining nonzero even at infinite separation as the signature of dynamical buildup of long-range entanglement [3]. Another prediction from tDMRG [4] shows that interaction of spin-polarized current pulses with the surface of antiferromagnetic Mott insulator (AFMI) will transmute zero expectation value of AFMI localized spins into nonzero values.

[1] K. Dolui, M. D. Petrovic, K. Zollner, P. Plechac, J. Fabian and B. K. Nikoli c, Proximity spin-orbit torque on a two-dimensional magnet within van der Waals heterostructure: Current-driven antiferromagnet-to-ferromagnet reversible nonequilibrium phase transition in bilayer CrI3, Nano Lett. 20, 2288 (2020).
[2] A. Zholud, R. Freeman, R. Cao, A. Srivastava, and S. Urazhdin, Spin transfer due to quantum magnetization fluctuations, Phys. Rev. Lett. 119, 257201 (2017).
[3] M. D. Petrovic, A. E. Feiguin, P. Plechac, and B. K. Nikolic, Spintronics meets density matrix renormalization group: Quantum spin torque driven nonclassical magnetization reversal and dynamical buildup of long-range entanglement, Phys. Rev. X 11, 021062 (2021).
[4] M. D. Petrovic, P. Mondal, A. E. Feiguin, and B. K. Nikolic, Quantum spin torque driven transmutation of antiferromagnetic Mott insulator, Phys. Rev. Lett. 126, 197202 (2021).