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Poster abstract booklet

Shift photocurrent vortices from topological polarization textures

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Recent work has shown that moiré materials can host topologically non-trivial polarization textures in real space [1-2]. However, the experimental verification of such textures has proven difficult. We show that these polarization textures are directly responsible for the formation of shift photocurrent vortices in real space [3], thus allowing for an experimental method wherein the former can be deduced from sub-diffraction photocurrent spectroscopy measurements [4] of the latter. Particularly, using non-Abelian Berry connections within a quantum-geometric framework [5], we analytically show that for materials hosting topologically trivial bands, the shift photocurrents are antiparallel to the electronic polarization [3]. Additionally, tight-binding and ab initio calculations rooted in twisted hexagonal boron nitride are used to show that the shift photocurrent does indeed exhibit a vortex-like structure analogous to the electronic polarization as predicted for a range of optical frequencies exciting transitions at the Brillouin zone edge [3]. Our findings thus highlight the topological nature of photocurrent excitations in non-centrosymmetric moiré materials and hence provide a sought-after strategy for the experimental detection of the polar meron-antimeron networks predicted in them [1].

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Theoretical Analysis of Topological superconductivity in moiré bilayers

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Moiré transition metal dichalcogenide (TMD) bilayers provide an ideal platform to explore strongly correlated electronic phases. Here, we consider both twisted WSe_2 homobilayer and untwisted WS_2/WSe_2 heterobilayers within t-J, t-J-V and t-J-U-V models. The order parameter is characterized by a stable topological non trivial singlet triplet mixed states. We find that by changing the displacement field, one can tune the balance between the singlet and triplet contributions to the pairing for the homobilayer case. Morover, we also consider the longer-range hopping and exchange interaction terms have minimal impact on the superconducting symmetry, whereas intersite Coulomb repulsion V suppresses the pairing. Nevertheless, the superconducting state remains stable within realistic parameter regime in both systems. Then we see the effect of nematic phase ordering under appropriate conditions. These findings highlight the interplay between moiré band topology, electronic correlations, and symmetry-breaking interactions, shedding light on unconventional superconductivity in TMD moiré systems.

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Non-periodic Boundary Conditions for Euler Class and Dynamical Signatures of Obstruction

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Abstract (max 200 words)

While the landscape of free-fermion phases has drastically been expanded in the last decades, recently novel multi-gap topological phases were proposed where groups of bands can acquire new invariants such as Euler class. As in conventional single-gap topologies obstruction plays an inherent role that so far has been only incidentally addressed. We here systematically investigate the nuances of the relation between the non-Bravais lattice configurations and the Brillouin zone boundary conditions (BZBCs) for any number of dimensions. Clarifying the nomenclature, we provide a general periodictization recipe to obtain a gauge with an almost Brillouin-zone-periodic Bloch Hamiltonian both generally and upon imposing a reality condition on Hamiltonians for Euler class. Focusing on three-band C2 symmetric Euler systems in two dimensions as a guiding example, we present a procedure to enumerate the possible lattice configurations, and thus the unique BZBC possibilities. We establish a comprehensive classification for the identified BZBC patterns according to the parity constraints they impose on the Euler invariant, highlighting how it extends to more bands and higher dimensions. Moreover, by building upon previous work utilizing Hopf maps, we illustrate physical consequences of non-trivial BZBCs in the quench dynamics of non-Bravais lattice Euler systems, reflecting the parity of the Euler invariant. We numerically confirm our results and corresponding observable signatures, and discuss possible experimental implementations. Our work presents a general framework to study the role of non-trivial boundary conditions and obstructions on multi-gap topology that can be employed for arbitrary number bands or in higher dimensions.

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Quantum spin liquid in the 2D-arrays of qudit-based Rydberg atoms

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Neutral (Rydberg) atom arrays have emerged as a versatile candidate for the embedding of hard classical optimization problems. Prior work [1] has focused on mapping problems onto finding the optimal graph coloring natively encoded into qudit-based Rydberg Hamiltonian. In this work, we focus on using the qudit-based Rydberg systems to numerically probe for gapped spin-liquid states with non-trivial long-range entanglement with Rydberg atom platforms as previously done in [2]. Besides, we analyze toward implementing gapped spin liquid with higher order than Z_2 and possibility for engineering topological excitation with non-abelian anyonic statistics.

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Thanks for Prof. C. Stuart Adams, supervisor of the first author during his PhD, and Prof. Jonathan D. Pritchard for a fruitful discussion about the experimental perspective of Rydberg-qudit implementation. Most importantly, all coauthors who have guided the first author through the world of topological matter research and how to perform necessary numerical simulation with Tensor networks.

A Local Semion-to-Qubit Mapping

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Since their discovery [1], topologically ordered phases have shown a plethora of exotic features, including topological ground state degeneracy, long-range entanglement, and emergent anyonic excitations in two-dimensions. The study of such systems has also been motivated by their potential to be used for quantum error correcting codes [2, 3] as they offer intrinsic topological protection of information that can be used in future quantum memories.

Given the emergence of anyonic excitations, it is natural to study the possible phases and dynamics of these anyons directly [4]. The use of existing digital quantum computers to simulate these systems is particularly exciting. However, to achieve this, we require mappings from anyons to qubits.

To account for long-range entanglement, we use the local fermionic Derby-Klassen mapping [5] as a starting point and describe two approaches to define hopping operators that can simulate anyonic statistics.

Starting from this mapping and restricting our search to semions, we first redefine the particle hopping operators and show their non-trivial commutation relations using the language of TQFT. Secondly, we tackle the problem from the perspective of String-Net models [6] and write edge operators in terms of open Wilson Strings. We conclude by drawing comparisons between the two approaches.

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Acknowledgments

Poster:
Kekulé order from diffuse nesting near higher-order Van Hove points

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Translation symmetry-breaking order is assumed to be suppressed by the lack of Fermi surface nesting near certain higher-order Van Hove singularities (HOVHS). We show the anisotropic band-flattening inherent to such HOVHS, combined with broadening of the Fermi surface due to elevated critical temperatures, results in the Fermi surface becoming approximately nested at a wavevector unrelated to the precise shape of the Fermi surface—leading to a $\sqrt{3} \times \sqrt{3}$ Kekulé density wave formation. The effect is demonstrated using unbiased renormalization group calculations for a model of the breathing kagome lattice. Our mechanism—termed *diffuse nesting*—represents an entirely new notion in the study of Fermi surface instabilities.

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Development of a Cryogenic Quantum Twisting Microsope

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Quantum Twist Microscopy (QTM) is a novel technique that enables energy- and momentum-resolved tunneling spectroscopy through continuous, in-situ twisting of van der Waals materials. It has already demonstrated itself to be a versatile and powerful tool for studying band structures, both at room temperatures by revealing interesting electron-electron interaction effects **(1)**, as well as at low temperatures by clarifying the phonon spectrum in TBG **(2)** and the flat-bands in MATBG **(3)**.

We already improved upon the original work by the group of Shahal **(4)**, by assessing higher energies and improving measurement resolution. The next milestone in development is a cryogenic QTM, which allows us to probe delicate low-energy band features which otherwise get thermally smeared out at room temperatures.

We report progress on a home-built AFM setup using compact piezo-scanners and rotators compatible for a cryostat sample holder. Our cryostat, capable of 10mK base temperature and equipped with a vector magnet, lets us access temperatures and phase spaces unprecedented for a QTM. We showcase the custom made QTM tips, which are adapted from commercial, piezoresistive AFM cantilevers. Finally, we demonstrate successful operation of our custom AFM at room temperature, using a custom QTM tip.

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Structural investigation of B20 chiral compounds using high-resolution TEM

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Abstract: Topological chiral semimetals with a non-centrosymmetric cubic B20-type structure (space group $P2_13$) are notable for their chirality in crystal, magnetic, and electronic structures [1]. The chiral B20-compounds lack inversion and mirror symmetries but retain rotational symmetries. In magnetic B20-materials, broken inversion symmetry and strong spin-orbit coupling lead to the Dzyaloshinskii-Moriya interaction, enabling chiral magnetic excitations like Skyrmions. Nonmagnetic B20-compounds (e.g., CoSi, RhSi, PdGa, PtAl) exhibit multifold fermions due to topological band crossings, resulting in higher Chern numbers and larger Fermi arcs than Weyl or Dirac semimetals [2,3]. Each enantiomorph of B20-crystals has a right- or left-handed atomic arrangement. Structural transformations between opposite-handed domains involve subtle atomic rearrangements, creating grain boundaries with distinct structural motifs. Unlike the A and B enantiomorphs of CoSi, these regions contain an inversion center, enabling local enantiomorph transformations, though with slightly higher total energy due to multi-atomic bond reorganization [4]. Identifying absolute handedness (left or right) of crystals is essential, as chirality significantly affects their physical properties. Local Convergent Beam Electron diffraction (CBED) obtained through TEM or SEM are sensitive to local chirality, allowing for accurate determination of crystal handedness. Our analysis focuses on chirality-dependent features in CBED patterns and demonstrates how quantitative pattern matching can reveal the chirality of B20 crystals. Examining the enantiomorph conversion region offers insights into the mechanisms of transition between enantiomorphs and may uncover energy barriers, symmetry-breaking effects, and pathways for controlling these transformations in chiral materials.

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Cavity-modified integer and fractional quantum Hall phases

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Coulomb interactions are central to quantum Hall physics, underpinning both the fractional quantum Hall (FQH) effect and the enhancement of the g-factor at odd integer filling factors. A recent experiment [1] has shown that coupling this system to an electromagnetic cavity in the ultra-strong light-matter coupling regime can significantly modify these interaction-driven phenomena. Notably, transport gaps at certain fractional filling factors increase, while the g-factor decreases. These effects are attributed to an effective, attractive, and long-range electron-electron interaction mediated by virtual cavity photons, especially when the cavity vacuum field exhibits strong spatial gradients.

We present a theoretical framework behind these observations [1, 2]. Both the enhancement of the FQH gap and the reduction of the g-factor stem from the same effective interaction. Using analytical calculations, we show that both effects scale collectively with system size, a consequence of the interaction's long-range character. The g-factor reduction arises from an additional exchange energy, while the FQH gap enhancement, obtained through the Girvin–MacDonald–Platzman (GMP) formalism, follows the same scaling behavior. To support the GMP results, we also perform Monte Carlo simulations on the sphere to compute the Composite Fermion Exciton (CFE) magnetoroton dispersion, which shows consistent agreement.

These findings show that cavity quantum electrodynamics can be a useful tool for tuning properties of topological correlated materials.

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Enhanced Biaxial Compressive Strain Tuning of 2D semiconductors via Hot Dry Transfer on Polymer Substrates

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Strain is an effective method for tuning the electronic and optical properties of two-dimensional (2D) semiconductors [1,2]. In this work, we demonstrate the transfer of unprecedent levels of uniform biaxial compressive strain to single-layer WS2 by pre-straining the samples at room temperature prior to cooling to cryogenic temperatures. Using a hot-dry-transfer method, single-layer WS2 samples were deposited onto thermally expanded polymeric substrates. As the substrate was allowed to cool to room temperature, the WS2 sample experienced a biaxial compression of up to ∼0.5 %, resulting in a shift in exciton energies of ∼40 meV compared to samples transferred at room temperature. Further cooling of the pre-strained samples from room temperature down to 4K led to a total substrate compression level of up to ∼1.7 %. This induced a significant modulation of exciton energies, corresponding to bandgap energy changes, in the single-layer WS2 of ∼200 meV, surpassing previous results by more than 50 meV and indicating larger induced levels of biaxial compressive strain. Furthermore, our findings revealed a temperature dependence of gauge factor values with temperature, with strain transfer efficiency at cryogenic temperatures exceptionally high.

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Quantum twisting microscopy at cryogenic temperatures

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For decades, scanning tunneling microscopy (STM) [1] has allowed us to visualize and probe the electronic structure of materials at the atomic scale. By measuring tunneling currents with extreme spatial resolution, STM reveals the local density of states, enabling direct insights into quantum behaviors, surface properties, and electronic phenomena in solid-state systems. The recent invention of the Quantum Twisting Microscope (QTM) [2] builds on this principle and even allows to probe the energy dispersion in reciprocal space. This is achieved by spanning a monoatomic layer of graphene over a flat micrometer sized pyramid, and measuring the momentum-conserving tunneling current to a graphene device, which maps out the Bloch wavefunction. As a result, the characteristic Dirac cone in graphene can be visualized, and unlike techniques such as angle-resolved photoemission spectroscopy (ARPES), the QTM can even probe hole-carriers. Here we show the development of a quantum twisting microscope at cryogenic temperatures. The dilution fridge insert will allow us to measure tunneling spectra at temperatures of ~10mK and in magnetic fields of up to 9T.

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Helical trilayer graphene in a magnetic field

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Helical trilayer graphene (HTG) features three layers of graphene successively twisted in the same direction, resulting in a supermoiré pattern and a real-space Chern mosaic [1]. At the so-called chiral limit, perfect flat bands arise with an ideal quantum geometry and Landau level (LL)-like properties. In this work [2], we investigate how a perpendicular magnetic field influences HTG, focusing on its interaction with the intrinsic LL-like states of HTG's flat bands. We find that the LL structure of hTG wavefunctions persists, preserving band flatness even at finite magnetic fields. The external magnetic field combines with an internal effective field associated to the wavefunctions of HTG and leads to topological transitions when the two fields cancel each other. Within a given valley, this cancellation occurs asymmetrically for the two field directions, leading to distinct topological transitions and two different Hofstadter spectra. We also identify a set of hidden wave functions that appears at the transition points and induce higher Chern numbers in the flat bands.

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The topological revival of FeSe

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FeSe has been one of the most studied Fe-based superconductors in the last two decades exhibiting a plethora of exciting phases including unconventional superconductivity, nematic order, magnetism, orbital-selective correlations and structural transitions, to mention a few. Only in recent years the possibility of topologically non-trivial phases has been discussed in the sister compound FeTeSe. In the present work we find that FeSe under uniaxial strain is a candidate for a rich variety of topological phases not previously reported. For that we perform electronic structure calculations of FeSe under various conditions of uniaxial strain, first at the level of density functional theory (DFT), and classify the topology of the resulting bands by means of Topological Quantum Chemistry (TQC) and symmetry indicators. We find that compression and expansion are effective ways of inducing topological transitions in FeSe and obtaining a topological insulating phase. Since correlation effects are important in FeSe, we further perform DFT+DMFT calculations for the various strained structures. The results suggest that some topology classification done at the level of DFT survives the correlation-induced renormalization of the Fe 3d bands. Our results indicate a revival of, yet unexplored, topological properties in FeSe and related compounds.

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Manifestation of the quantum metric in chiral lattice systems

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The Aharonov-Bohm effect demonstrates how a vector potential can induce a phase shift in electron wave-packets, even in regions with zero magnetic fields, due to a magnetic flux obstructing space. This highlights how a system's geometry can influence its dynamics. In this work, we show that measuring a dynamical observable called the mean chiral displacement, of delocalized wavefunctions, in a chiral-symmetric process reveals information about the system's quantum metric. This result generalizes the applications of mean chiral displacement from topology to geometry [1]. To validate these findings, one- and two-dimensional quantum walks are implemented using custom liquid crystal devices [1] and Spatial Light Modulators (SLMs) [2,3]. The reconfigurability of SLMs enables access to various quantum processes with distinct topological and geometrical features [2,3].

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Sub-baths cluster dynamical mean field theory (SB-CDMFT)

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The accuracy of numerical resolution methods for strongly correlated electron systems depends on system size, with computational costs growing exponentially. Cluster dynamical mean-field theory (CDMFT), coupled with exact diagonalization (ED) impurity solver face significant limitations due to this exponential growth of the Fock basis when simulating bath sites connected to clusters. We introduce an alternative CDMFT approach that decomposes the bath into sub-baths using system symmetries. Instead of considering a single bath, only one sub-bath actively participates in ED, dramatically reducing computational cost while preserving essential physics. This technique enables more scalable representation of the lattice's influence on the cluster, effectively increasing the number of bath sites included in the procedure. Our method was validated by benchmarking a one-dimensional model against exact solutions. Results confirm successful reproduction of key physical properties[1] while allowing extended bath representation at a fraction of typical computational expense. The approach captures the full system's behavior through judicious subdivision based on symmetries, while achieving significant computational savings. This development has promising implications beyond CDMFT, as the same methodology could be adapted to other numerical techniques such as the Dynamical Cluster Approximation (DCA), offering a scalable solution for studying strongly correlated systems.

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Characterizing Mott Insulators

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On one hand, elementary band representations (EBRs) have proven to be efficient tools for diagnosing topology in non-interacting insulators [1]. On the other hand, single particle Green's functions are a well-understood object used to analyze strongly correlated matter. It follows that an application of EBRs to SPGFs would allow for high throughput calculations on real materials boasting strong interactions. In this poster, we show that the machinery pertaining to EBRs can be applied to SPGFs directly. Moreover, we show how the one-body reduced density matrix can be used to analyze the effective one-body orbitals of the interacting many-body system. In particular, we examine a model having two distinct Mott phases that can be characterized by these techniques.

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Topological Andreev surface states in d-wave superconductors

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Over the past half-century, condensed-matter physics has largely revolved around three main themes—superconductivity, topology and strong correlations—whose interplay has spawned a host of exotic phases. A striking illustration of this interplay appears in cuprate superconductors: their chiral symmetry endows nodal quasiparticles with a nontrivial winding number, defined by mapping from loops in momentum space into the rotation group SO(2). This integer winding directly implies the existence of zero-energy states localized at certain edges of the superconductor, forming flat bands between the projections of superconducting nodes of opposite winding number. Although zero-bias conductance peaks in tunneling have long hinted at these states, a momentum-resolved characterization has been elusive—posing challenges for the unequivocal identification. Here, we combine analytical and numerical modeling with ARPES measurements to provide evidence for these topological edge modes in a momentum-resolved measurement.

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Altermagnetism without Crystal Symmetry

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Altermagnetism is a collinear magnetic order in which opposite spin species are exchanged under a real-space rotation. Hence, the search for physical realizations has focussed on crystalline solids with specific rotational symmetry. Here, we show that altermagnetism can also emerge in non-crystalline systems, such as amorphous solids, despite the lack of global rotational symmetries. We construct a Hamiltonian with two directional orbitals per site on an amorphous lattice with interactions that are invariant under spin rotation. Altermagnetism then arises due to spontaneous symmetry breaking in the spin and orbital degrees of freedom around each atom, displaying a common point group symmetry. This form of altermagnetism exhibits anisotropic spin transport and spin spectral functions, both experimentally measurable. Our mechanism generalises to any lattice and any altermagnetic order, opening the search for altermagnetic phenomena to non-crystalline systems.

High-Throughput Discovery of Perturbation-Induced Topological Magnons

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Making reliable and systematic predictions about the material realization of topological magnons has been a major challenge, due to the lack of neutron scattering data for most materials and the absence of reliable ab initio calculations for magnons. In this work, we significantly advance the symmetry-based approach for identifying topological magnons through developing a fully automated algorithm, utilizing the theory of symmetry indicators, that enables a highly efficient and large-scale search for candidate materials hosting perturbation-driven topological magnons. This progress not only streamlines the discovery process but also expands the scope of materials exploration beyond previous manual or traditional approaches, offering a powerful tool for uncovering novel topological phases in magnetic systems. Performing a large-scale search over all 1649 magnetic materials in the Bilbao Crystallographic Server (BCS) with a commensurate magnetic order, we discover 387 perturbation-induced topological magnon materials, significantly expanding the pool of topological magnon materials and showing that more than 23% of all commensurate magnetic compounds in the BCS database are topological. We further discuss examples and experimental accessibility of the candidate materials, shedding light on future experimental realizations of topological magnons in magnetic materials. We conclude by discussing recent experimental collaborations on observing Weyl magnons in a noncoplanar antiferromagnet $MnTe_2$.

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Moiré-trapped Charge Density on RuO2(110) / Ru(0001)

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The recently proposed altermagnetism in RuO2 has sparked significant theoretical and experimental interest in this compound. Derived from ARPES data, the strong Fermi surface nesting in RuO2 suggests a susceptibility to electron correlations. Using the density matrix renormalization group, we demonstrate that this nesting favours a charge density wave instability over a spin density wave, which is stabilized by the moiré potential of the Ru substrate. We present preliminary experimental evidence for this charge density wave and a zero-bias anomaly. These findings illuminate the interplay between the Ru metal substrate and the RuO2 oxide, advancing this topical material.

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Spin and charge chiral magnetotransport effects in spin Weyl altermagnets

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In this work [1] we investigate the magnetotransport signatures of a tight binding model for spin Weyl altermagnetism [2] by using the semiclassical equations of motion of an electronic wavepacket [3]. Here, we show that the spin polarized chiral magnetic effect emerges as the leading order contribution to the chiral transport in spin Weyl altermagnets, which is posed by the crystal rotation connecting the spin sublattices. Besides, a higher order charge magnetoresistance current appears as it is not forbidden by neither time reversal nor inversion symmetries, but it is a consequence of the nontrivial chiral chemical potential of the system. We demonstrate that these responses are not dramatically sensitive to the spin orbit interaction or the nonrelativistic spin splitting in a wide range of energies. Instead, they are a consequence of the orbital configuration, the presence of spin Weyl points and the rotational symmetry connecting the spin sublattices. This research reveals the role of spin symmetries to uncover unforseen chiral responses in Weyl altermagnets, and it also suggests further exploration to identify new classes of magnetic Weyl semimetal phases in realistic quantum materials.

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Spin-dependent transport through edge states in 2D semi-Dirac materials with Rashba spin-orbit coupling and band inversion

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Our research focuses on the field of low-dimensional materials, specifically two-dimensional systems described by the semi-Dirac model [1]. These systems exhibit an anisotropic dispersion relation, characterized by linear dependence in one momentum-space direction and quadratic dependence in the perpendicular direction. In the absence of spin—or equivalently, considering a single spin polarization—the system undergoes a topological phase transition under specific conditions, leading to the emergence of topologically protected edge states in finite-sized samples, spatially localized along either the upper or lower edge. Remarkably, only a single-momentum value, corresponding to a zero-energy mode, is topologically protected and can be rigorously founded on the Zak phase of the one-dimensional reduction of the Hamiltonian [2]. This study explores the effect of the Rashba spin-orbit coupling (RSOC) on this picture when the spin is included. The RSOC gives rise to spin-dependent edge states and provides additional topologically protected edge states. We also compute spin-resolved conductance through these edge channels, observing robust, tunable oscillations—attributable to spin precession induced by the effective Rashba magnetic field [3]. These results reveal how the RSOC enriches the edge-state physics of semi-Dirac systems and highlights the potential of anisotropic topological materials as platforms for controlling spin currents.

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Angle Resolved High Field Study of QHE regime of 3D Dirac Semimetal Cd3As2

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We present an angle-resolved high magnetic field transport study on the three-dimensional Dirac semimetal Cd_3As_2, focusing on Shubnikov–de Haas (SdH) quantum oscillations. By systematically varying the magnetic field orientation, we probe the anisotropy of the Fermi surface and disentangle contributions from bulk and surface transport channels. Our results reveal pronounced 3D bulk quantum oscillations[1], consistent with a Dirac-like linear dispersion, while also indicating the emergence of possible 2D surface states at specific orientations. The angle dependence of oscillation frequencies suggests transport channels in different oscillation frequencies. At high fields, we observe signatures reminiscent of a quantized Hall effect, pointing toward a possible 3D quantum Hall regime via Weyl Orbits[2], a phenomenon rarely observed in Dirac semimetals. These findings provide new insights into the interplay between dimensionality, topology, and magnetic quantization in Cd_3As_2, and highlight the potential for accessing exotic quantum phases in 3D topological materials under extreme conditions.

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[Hofstadter Butterfly Spectrum in relaxed Moiré systems.]

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Abstract

Several recent works [1-6] computed low-energy bands for relaxed TBLG systems by going beyond Bistritzer-MacDonald (BM) Hamiltonian [7] after including the effect of atomic relaxation. Here we shall present the effect of a transverse magnetic field on these low-energy moiré bands using a Green's function based method.

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Modulation of the Superconducting Phase Transition in Multilayer 2H-NbSe2 Induced by Uniform Biaxial Compressive Strain

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Strain is a powerful tool for tuning the properties of two-dimensional materials [1,2]. Here, we investigated the effects of large, uniform biaxial compressive strain on the superconducting phase transition of multilayered 2H-NbSe2 flakes. We observed a consistent decrease in the critical temperature of NbSe2 flakes induced by the large thermal compression of a polymeric substrate (>1.2%) at cryogenic temperatures. For thin flakes (~10 nm thick), a strong modulation of the critical temperature up to 1.5 K is observed, which monotonically decreases with increasing flake thickness. The effects of biaxial compressive strain remain significant even for relatively thick samples up to 80 nm thick, indicating efficient transfer of strain not only from the substrate to the flakes but also across several van der Waals layers. This work demonstrates that compressive strain induced from substrate thermal deformation can effectively tune phase transitions at low temperatures in 2D materials.

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Valence-bonds, spin liquids and unconventional criticality in a 1D Kondo insulator

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Abstract

We consider a one-dimensional multi-orbital Kondo lattice model and show that by tuning the kinetic energy of the itinerant electrons it is possible to stabilize Kondo insulators with non-trivial spin physics. In particular, depending on the size of the exchange coupling between the local moments, we find kinetic-energy-driven transitions between a featureless Kondo insulator and a valence-bond solid or a gapless spin liquid. We also provide evidence for an unconventional continuous phase transition between two featureless Kondo insulators distinguished by their quantum numbers under reflection symmetry.

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Spin Hall and Edelstein Effects in Novel Chiral Non-collinear Altermagnets

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Altermagnets are a newly discovered class of magnetic phases that combine the spin polarization behavior of ferromagnetic band structures with the vanishing net magnetization characteristic of antiferromagnets. Initially proposed for collinear magnets, the concept has since been extended to include certain non-collinear structures. A recent development in Landau theory for collinear altermagnets incorporates spin-space symmetries, providing a robust framework for identifying this class of materials. Here, we expand on that theory to identify altermagnetic multipolar order parameters in non-collinear chiral materials. We demonstrate that the interplay between non-collinear altermagnetism and chirality allows for spatially odd multipole components, leading to non-trivial spin textures on Fermi surfaces and unexpected transport phenomena, even in the absence of SOC. This makes such chiral altermagnets fundamentally different from the well-known SOC-driven Rashba-Edelstein and spin Hall effects used in 2D spintronics. Choosing the chiral topological magnetic material Mn_3IrSi as a case study, we apply toy models and first-principles calculations to predict experimental signatures, such as large spin Hall and Edelstein effects, that have not been previously observed in altermagnets. These findings pave the way for a new realm of spintronics applications based on the spin-transport properties of chiral altermagnets.

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Spin chirality in van der Waals antiferromagnet

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Abstract

Chirality-driven spin configurations hold great potential for advancing spintronics by enabling compact, energy-efficient memory devices and high-density data storage solutions. Here, we will present our experimental results of spin structures in 2D van der Waals magnet. These spin configurations exhibit distinct optical characteristics, arising from spin interactions influenced by external magnetic fields and thermal variations. The observed chiral optical responses serve as a highly sensitive probe for detecting non-collinear spin arrangements. Our findings highlight 2D magnetic materials and their heterostructures as promising candidates for reconfigurable spin-photonics and spintronic applications.

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Electron-phonon and Coulomb interactions in Weyl semimetals under strong magnetic fields and torsional strain

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Abstract

We study the presence of a strong magnetic field, in combination with torsional strain, over the electron-phonon and electron-electron interactions in a generic Weyl semimetal. This particular superposition of field and strain, modeled in the continuum approximation by an effective gauge field, leads to an asymmetric pseudo-magnetic field at each Weyl node with opposite chirality. Therefore, we also studied the role of nodal asymmetry on the properties of the system by means of the Wilson renormalization group and the corresponding Callan-Symanzik flow equations. By solving those, we discuss the evolution of the coupling parameters of the theory and analyze possible fixed points leading to strongly correlated phases.

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New materials for superconducting spintronics

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The realization of spin-triplet Cooper pairs is a key ingredient for superconducting spintronics. One promising route to achieve this task is by exploiting the strong intrinsic spin-orbit coupling of transition metal dichalcogenides (TMDs). In this work, we consider a TMD layer coupled to a conventional spin-singlet s-wave superconductor and demonstrate the emergence of spin-triplet superconducting correlations. We find that these spin-triplet pair correlations form in the TMD as a proximity-induced effect but also appear in the superconductor as an inverse proximity effect and as a nonlocal phenomenon that exists between the TMD and superconductor. Furthermore, we relate these emergent superconducting correlations to experimentally observable features in the density of states and conductance.

This work will partially build on results obtained within the ERC ODDSUPER project (ERC-2017-StG-757553)

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Topological superconductivity in Fibonacci quasicrystals

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We investigate the properties of a Fibonacci quasicrystal (QC) arrangement of a one-dimensional topological superconductor, such as a magnetic atom chain deposited on a superconducting surface. We uncover a general mutually exclusive competition between the QC properties and the topological superconducting phase with Majorana bound states (MBS): there are no MBS inside the QC gaps and the MBS never behaves as QC subgap states, and likewise, no critical, or winding, QC subgap states exist inside the topological superconducting gaps. Surprisingly, despite this competition, we find that the QC is still highly beneficial for realizing topological superconductivity with MBS. It both leads to additional large nontrivial regions with MBS in parameter space, that are topologically trivial in crystalline systems, and increases the topological gap protecting the MBS. We also find that shorter approximants of the Fibonacci QC display the largest benefits. As a consequence, our results promote QCs, and especially their short approximants, as an appealing platform for improved experimental possibilities to realize MBS as well as generally highlights the fundamental interplay between different topologies.

Tunable Rashba splitting in single Jayer Janus SbSeI via strain and electric field

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Materials exhibiting Rashba splitting (RS) and Rashba-like spin textures can convert charge current into spin current and enable the generation, detection, and manipulation of spin currents without an external magnetic field. Recently, the 2D SbSeI Janus monolayer (JL) was reported to be energetically, dynamically, and thermodynamically stable at room temperature, with a built-in electric field perpendicular to the surface. Using density functional theory-based electronic structure calculations, we demonstrate that broken out-of-plane mirror symmetry, combined with spin-orbit coupling (SOC), induces strong RS in SbSeI JL, enabling potential control over spin via an external electric field. The key parameters, Rashba energy (E_R), crystal momentum offset (k_R), and Rashba parameter (α_R) for SbSeI JL are found to be 39.3 meV, 0.050 $Å^{-1}$, and 1.57 eV·Å, respectively. Both strain and external electric fields effectively modulate SOC strength and control RS. We find that uniaxial strain induces significant anisotropy in band splitting, which may benefit anisotropic spin transport, while the α_R remains robust under biaxial strain up to ±4%. Moreover, applying an external electric field further enhances RS. For example, the α_R increases to 1.70 eV Å under the applied field of 1.12 V/nm.

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Unveiling Stacking-Dependent Band Structures in Graphene via Room-Temperature QTM

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The Quantum Twisting Microscope (QTM) has emerged as an exceptionally powerful and versatile tool for unveiling the band structure of two-dimensional materials with high resolution—even capable of resolving electron–electron correlations at room temperature [1-2]. With our home-built room-temperature QTM that leverages high-quality few-layer hBN tunnel barriers to achieve an unprecedented extended bias window ($|V_b| \leq 2.5$ V) and energy–momentum resolution, we explore the band structures of graphene comprising two to five layers. First, in bilayer graphene, we observe a pressure-tunable modification of the low-energy bands under applied local pressures up to ~1 GPa, indicative of interlayer coupling enhancement. Second, in four-layer graphene, we explored the momentum-resolved tunneling spectroscopy of an ABCB stacking graphene, revealing a unique band structure distinct from conventional Bernal stacks [3-4]. These measurements deepen our understanding of correlated states in rhombohedral graphene and motivate future cryogenic QTM studies.

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Superconductivity in In-Sn System

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The recent discovery of superconductivity in topological materials, such as topological semimetals and insulators, represents a significant advancement in the field of quantum materials, opening new avenues for exploration [1, 2]. Topological superconductors (TSCs) are unconventional superconductors characterized by a fully gapped superconducting bulk and conducting gapless surface states. These surface states host Majorana fermions, particles that are their own antiparticles, which are considered potential candidates for quantum qubits [3]. However, only a few intrinsic topological materials exhibit superconductivity, highlighting the need to discover new superconducting topological materials. Bimetallic superconducting alloys, which are less explored, offer a promising platform to realize topological superconductivity due to their strong spin-orbit coupling and non-trivial band structures [4, 5].

I will present the synthesis and detailed study of the structural and superconducting properties of In-Sn bimetallic alloys, specifically In_3Sn and $InSn_4$, using X-ray diffraction (XRD), transport, magnetization, and heat capacity measurements. These measurements indicate that both the samples emerge type-II, fully gapped superconductivity in the weak coupling limit. Additionally, these materials provide insight into the effects of spin-orbit coupling and topologically non-trivial surface states on superconducting properties, which is crucial for understanding topological superconductivity.

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Fracton-elasticity duality for a Wigner crystal and the “anti-Higgs mechanism”

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A classic work by Pretko and Radzihovsky [1] showed that the theory of elasticity can be dualised to a higher-rank gauge theory with the elastic defects (disclinations and dislocations) acting as charges. Motivated by it, we show that when the crystal lattice is composed of electrically charged particles, like in the case of a Wigner crystal, the resulting dual theory contains an additional gauge field sourced by vacancies and interstitials [2]. Unexpectedly, we find that upon a condensation of vacancies or interstitials the corresponding gauge field does not become massive – on the contrary, the number of massless modes in the system increases. We dub this mechanism the “anti-Higgs mechanism”.

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Exploring Topological and Disorder Physics with Coaxial Cable Networks

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We demonstrate that coaxial cable networks are an excellent platform for experiments in topological and disorder physics. They sit between discrete electronic circuits and microwave photonic implementations. A network of coaxial cables can be mapped onto a tight-binding model, where each cable represents a hopping term inversely related to its impedance. The cables are joined by SMA connectors, so it is easy to make an ensemble of disordered structures. The network scattering parameters, measured using a vector network analyser, can be used to determine the Green's function corresponding to the Hamiltonian, so all the topological properties are accessible.

Moreover, we use our cable networks to implement a Su-Schrieffer-Heeger (SSH) chain and observe the edge states for different terminations. By adding disorder to the chain, we demonstrate excellent topological protection of a zero-energy state. We also study the transition between the two topological phases of the disordered chain and show that it is accompanied by delocalised states and the appearance of a Dyson singularity in the density of states. We observe a similar Gade singularity in the ensemble density of states for a small graphene sheet, where disorder is created by removing lattice sites from the network.

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Supercell Wannier Functions and Emergent Kondo Lattices in Topological Bands

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Abstract

Twisted transition metal dichalcogenide (TMD) heterostructures are a highly-tunable platform for realizing many-body correlated states. In particular, they allow studying the interplay between band topology and strong electronic correlations in experimentally realizable systems. Here, we show that in addition to conventional fractional quantum Hall states, topological bands in twisted TMDs can host a topological Mott insulator with broken translation symmetry and zero net magnetization at fractional commensurate fillings. In a topological band, a Mott-like picture of charges forming local moments is in apparent conflict with the inability to form exponentially localized Wannier functions. We have developed a loophole that leverages translation symmetry breaking to exponentially localize a subset of charge degrees of freedom, providing a concise heuristic to understand the stability of Mott insulators at fractional filling in the presence of topological obstructions. We use this construction to explain the possibility for a topological Mott insulator in the Bernevig-Hughes-Zhang model and twisted MoTe2, and study their competing magnetic orders using exact diagonalization.

SymmetricTightBinding.jl: A Julia Package for Building Symmetry-Constrained Tight-Binding Models

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Introducing *SymmetricTightBinding.jl*, a unique Julia package designed to construct tight-binding Hamiltonians with spatial symmetries. By utilizing group-theoretical data from the Crystalline.jl ecosystem, this package offers the automatic generation of minimal tight-binding models that align with the space group (or plane group) symmetry of a crystal structure. The approach, which is based on symmetry-adapted basis functions like those from elementary band representations (EBRs), produces tight-binding models that inherently respect all symmetry-imposed constraints.

As a case study, we demonstrate the practical application of SymmetricTightBinding.jl to graphene, which is modeled as a 2D lattice with plane group *p6mm*. Starting from a single p_z orbital at each carbon site, we use the package to recover the well-known symmetry-protected Dirac cones at the *K* and *K′* points of the Brillouin zone. We further show how the package facilitates controlled symmetry breaking, enabling systematic studies of gapped phases.

This versatile tool is designed to streamline the construction and exploration of tight-binding models for a wide range of crystalline systems. It serves as a bridge between symmetry analysis and numerical modeling, making it particularly well suited for high-throughput studies of topological materials and model Hamiltonians.

A new perspective on defects in topological insulators

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Abstract (max 200 words)

When characterizing robust localized states in topological insulators, it is common to focus on the existence of a gapless energy. However, this approach doesn't often work when characterizing robust modes localized around defects in topological insulators. This is because surface states in the topological insulator already make the energy spectrum gapless. As a result, even if gapless modes emerge, it is tough to judge whether they are robust modes localized around defects or surface states.

In this presentation, we will explain that non-Hermitian topology could help identify modes localized at defects in a Hermitian topological insulator [1]. If time permits, we will also briefly mention related phenomena.

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Acknowledgments

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Excitonic and magnetic phases in doped WTe_2 monolayers: a Hartree-Fock approach

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Transport and local spectroscopy measurements have revealed that monolayers of tungsten ditel- luride (1T′-WTe2) display a quantum spin Hall effect and an excitonic gap at neutrality, besides becoming superconducting at low electron concentrations. With the aim of studying the competi- tion among different broken-symmetry phases upon electron doping, we have performed extensive Hartree-Fock calculations as a function of electron density and Coulomb interaction strength. At charge neutrality, we reproduce the emergence of a spin density wave and a spin spiral state surround- ing a quantum spin Hall insulator at intermediate interaction strengths. For stronger interactions, the spin spiral is disrupted by a state breaking both inversion and time-reversal symmetries (but not their product) before the system becomes a trivial band insulator. With electron doping the quantum spin Hall insulator evolves into an easy-plane ferromagnet due to a Stoner-like instability of the conduction band. This phase competes energetically with the spin spiral state. We discuss how our results may help to interpret past and future measurements.

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Non-Equilibrium Mechanical Torque for Chirality Measurement

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The notion of chirality could mean either structural asymmetry in the chemistry context or, from physicist's perspective, topological properties of carriers in solids. In both cases the chiral properties are believed to strongly influence observable chemical reactions or propagation of charge and heat carriers. Developing a robust experimental test for chiral properties of either crystal structure or the carriers is therefore of great interest for both physics and chemistry communities. In the present work we suggest doing so by probing the chirality of TR-symmetric systems with mechanical torque measurement. Namely, we show that driving a system out of equilibrium with temperature gradient (or electric field to excite electrons) would result in uncompensated angular momentum and mechanical torque. Calculations are made for both phonons (insulating case) and electrons (metallic case) carrying angular momentum. For phonons, our theoretical findings stand in reasonable agreement with the recent experiment [1]. For electronic subsystem, we discuss both cases of structural and topological electronic chirality probe.

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Microscopic Mechanism of Anyon Superconductivity Emerging from Fractional Chern Insulators

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Fractional quantum Hall (FQH) states and superconductors typically require contrasting conditions, yet recent experiments have observed them in the same device. A natural explanation is that mobile anyons give rise to superconductivity; however, this mechanism requires binding of minimally charged anyons to establish an unusual energy hierarchy. This scenario has mostly been studied with effective theories, leaving open the question of how anyon superconductivity can arise from repulsive interactions. Here, we show that such an energy hierarchy of anyons arises naturally in fractional Chern insulators (FCIs) at fillings $\nu = 2/(4p \mp 1)$ when they are driven toward a quantum phase transition into a ``semion crystal''---an exotic charge-density-wave (CDW) insulator with semion topological order. Near the transition, Cooper-pair correlations are enhanced, so that a conventional charge-2e superconductor appears with doping. Guided by these insights, we analyze a microscopic realization in a repulsive Hubbard-Hofstadter model. Tensor network simulations at $\nu = 2/3$ reveal a robust FCI that, with increasing interactions, transitions into the semion crystal. Finding a stable semion crystal in such a minimal model highlights it as a viable state competing with conventional CDW and FQH states. In the vicinity of this transition, we find markedly enhanced Cooper pairing, consistent with our theory that the 2e/3 anyon is cheaper than a pair of isolated e/3 anyons. Our framework unifies recent approaches to anyon superconductivity, reconciles it with strong repulsion and provides guidance for flat band moir\'e materials such as recent experiments in twisted MoTe$_2$.

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Light-Induced Interlayer Raman Forces in 2D Materials

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In general, the Raman effect is a three-wave mixing process, being inelastic scattering of a light generation or annihilation of a vibration: a phonon in condensed matter systems. We instead consider the phonon as the outgoing response from a second-order light-matter interaction, meaning we observe a second-order atomic force response, called the Raman force [1]. We look at the case where the phonon is rectified, analogous to a DC photocurrent, meaning we observe a change in the equilibrium positions of atoms (displacive motion) on top of oscillatory (impulsive) motion [2]. Here, we analyse the second-order Raman force susceptibility theoretically using a Feynman diagrammatic approach, describing electron-phonon coupling using a force constant model [3], from which we identify the displacive and impulsive components for responses to both linearly and circularly-polarised light. We elucidate the quantum geometric dependence of the key components, as well as the additional parameters which determine the strength and sign of each response, and the effect of symmetry. We also obtain numerical and analytical low-energy model results for an interlayer shear force in the bilayer Haldane model, quantifying and visualising the Raman force susceptibility over a range of incident frequencies of light and (T-symmetry breaking) Haldane gaps.

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Eliashberg theory and superfluid stiffness of band-off-diagonal pairing in twisted graphene

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Band-off-diagonal superconductivity has recently been proposed as a pairing state in twisted graphene systems [1]. Mean-field theory suggests it arises naturally from both intervalley electron-phonon coupling and fluctuations near correlated insulators, and it can exhibit both nodal and gapped regimes, consistent with scanning tunneling microscopy. Here [2], we study band-off-diagonal pairing within Eliashberg theory. Despite the additional frequency dependence, the leading-order description of both intervalley coherent fluctuations and intervalley phonons exhibits a symmetry prohibiting the admixture of an intraband component to the interband pairing state. A mixing of even- and odd-frequency components emerges due to the reduced flavor degrees of freedom in the normal state, and the superconducting phase transition can become discontinuous. Analytic continuation reveals an enhanced electronic spectral weight below the order-parameter energy compared to band-diagonal pairing. Finally, we also study the superfluid stiffness of band-off-diagonal pairing, taking into account multiband and quantum geometry effects. It is shown that for s-wave and chiral momentum dependencies - conventionally fully gapped - an interband structure reduces the temperature scale below which the stiffness saturates. For the chiral state, this scale can even be suppressed all the way to zero temperature, leading to a complex competition of multiple dispersive and geometrical contributions. These findings suggest that interband pairing could explain recent superfluid stiffness measurements in twisted multilayer graphene [3].

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Thermoelectric Studies of Heavy Fermion Physics in Magic-Angle Twisted Bilayer Graphene

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Magic-angle twisted bilayer graphene (MATBG) has been predicted to host coexisting heavy and light charge carriers, as described by the recently developed topological heavy fermion model [1,2]. While transport and spectroscopic measurements support this model, direct experimental verification has been limited. In contrast to conventional transport coefficients, the thermoelectric measurements provide direct insight into the interplay between charge, heat, and entropy flow, making it particularly suited for revealing the interplay between interplay of light, long-lived and heavy, short-lived electron bands near the Fermi level in MATBG[3]. In this study, we investigate the thermoelectric response of MATBG to reveal signatures of strong correlations, offering evidence of the heavy fermion physics.

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Tunable Exceptional contours - ellipse, lines and points - in unconventional magnetic junctions

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Abstract

The existence of exceptional points (EPs) – where both eigenvalues and eigenvectors converge – is a key characteristic of non-Hermitian physics [1-2]. A newly-discovered class of magnets – termed as altermagnets (AMs) – is characterized by a net zero magnetization as well as spin-split bands [3-4]. On the other hand, p-wave magnets are characterized by their unusual odd parity [5]. In this work, we propose the emergence of tunable EPs at AM-ferromagnet (FM) junctions. We demonstrate that the positions of these emergent EPs can be tuned using an external applied magnetic field and show that for a critical value of the applied magnetic field the EPs can annihilate [6]. Notably, the number and position of the EPs crucially depends on the type of AM and its orientation with respect to the FM. In another follow up study we demonstrate that the interface of p-wave magnets and FM hosts extended version of EPs i.e., exceptional lines and rings, which can be controlled via the orientation of the p-wave Néel vector. We present the origin of these exceptional contours based on symmetry and characterize them using phase rigidity [7]. Our work puts forth a promising platform for exploration of non-Hermitian physics in novel classes of magnetic materials.

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Floquet Theory in Condensed Matter Systems via *ab-initio* calculations

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Modern technology enables the precise control of matter through light-matter interactions. Among the various strategies, periodically driven quantum systems stand out, with Floquet theory providing a powerful framework to describe their dynamics [1]. This has led to the discovery of phenomena such as topological phases [2], quantum phase transitions [3], and dynamical localization [4], where a time-periodic driving field prevents the spread of a localized wave packet.

In this work, we present a method to compute the Floquet quasienergy spectrum in extended systems [5]. The approach employs the velocity gauge and a truncated Hilbert space to construct and diagonalize the time-periodic Hamiltonian. As a case study, we analyze a one-dimensional chain using the tight-binding approximation, obtaining excellent agreement with analytical results and correctly identifying the onset of dynamical localization. The method is further applied to two-dimensional systems, including graphene and Kagome lattices, focusing on quasienergy band interactions under different driving conditions. To extend the analysis to realistic materials, we compute matrix elements from density functional theory using the Wannier formalism. This allows us to investigate materials of current interest, such as SnTe, and explore their Floquet-engineered properties [6].

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[Disorder-Induced Topological Phase Transition in the Integer Quantum Hall Effect]

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We numerically investigate the disorder-induced phase transition in the integer quantum Hall effect [1] (IQHE) on a two-dimensional lattice. Our focus is on the evolution of extended states under increasing disorder and its consequences for the system's topological character. By examining localization properties across multiple Landau bands [2], we probe the critical features of the transition and their dependence on energy and model parameters. This study aims to deepen the understanding of disorder-driven topological phase transitions, highlighting the interplay between localization, criticality, and topological invariants in quantum Hall systems.

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Altermagnetism in the orthorhombic Pnma structure through group Theory and DFT Calculations

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Magnetism is a fundamental aspect of condensed matter physics, crucial to many technologies. Magnetic solids are broadly classified as ferromagnets (FM) or antiferromagnets (AFM). FMs exhibit net magnetization and spin-split band structures in reciprocal space, breaking time-reversal symmetry T in the non-relativistic (NR) limit. In contrast, conventional AFMs have compensating antiparallel magnetic moments, leading to negligible macroscopic magnetization and preserved T symmetry in the reciprocal space. Recent studies reveal that certain AFM-like materials exhibit FM-like features—such as T-breaking and NR spin-splitting—despite vanishing net magnetization [1]. This new phase is termed altermagnetism (AM) [2]. We investigate two centrosymmetric materials —orthorhombic BiFeO3 (BFO) and CaMnO3(CMO)—using Density Functional Theory (DFT) and group theory. Both are insulating with a preferred AFM order, yet show significant spin splitting in the ky-kz plane, while preserving degeneracy in other planes. Using invariant theory, we derive the effective Hamiltonian near the Gamma point and identify magnetic space groups (MSGs) within the Pnma space group that support NR spin-splitting. We also examine the role of spin-orbit interaction (SOI), revealing weak ferromagnetism in both compounds. Finally, we calculate the anomalous Hall conductivity as a probe of this ferromagnetic component [3].

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Phase diagram of amorphous quantum spin Hall insulator

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In light of recent progress in the study of amorphous topological insulators, we investigate the effects of amorphization on the topological properties of a prototypical model of a two-dimensional quantum spin Hall insulator. Using the local marker introduced for Dirac models in [2][3], we obtain the phase diagram of the system as a function of the mass parameter and disorder strength. We observe that the phase diagram can differ drastically depending on the extent of hopping in the crystalline limit as governed by the choice of hard cut-off R. Consequently, under the influence of structural disorder, a system can either undergo a phase transition from non-trivial to trivial (N$\rightarrow$T) regime or from a trivial to non-trivial regime (T$\rightarrow$N). Apart from these, we find that at specific values of R, the system can exhibit a surprising behaviour where even a small structural distortion can induce a large perturbation leading to a disorder-driven re-entrant transition from a non-trivial to a trivial state and then back to non-trivial state (N$\rightarrow$T$\rightarrow$N) as the disorder strength increases.

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Excitons in solids, at a TD-DFT cost

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GW based calculations in conjunction with the Bethe-Salpeter equation (BSE) have become thestandard approach to analyze excitons in condensed matter. Here we show that this analysis is possible for solids within linear response time dependent density functional theory (TDDFT). Recently, we have shown that hybrid functionals are reliable enough to obtain accurate optical gaps for bulks and surfaces, and 2D systems. In this study we investigate a complex bulk halide double perovskite, two prototypical reconstructed surfaces, and two van der waals materials with various exchange correlation functionals. We show that an accurate exciton analysis is now possible with XC functionals, namely certain meta-GGA (TASK) and hybrid approximations (PBE0, HSE, WOT-SRSH), at a significantly reduced cost compared to many-body perturbation based approaches.

Shubnikov-de Haas Oscillations in Orbital-Hall Candidate $PtSe_2$

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The van der Waals-layered Dirac semimetal $PtSe_2$ is a strategic material system for prospective applications in electronics, spintronics [1], and orbitronics. In particular, $PtSe_2$ is relevant for prospective orbital-Hall-effect (OHE)-based devices, thanks to its air-stability, large predicted orbital currents [2] and inherent spin-orbit coupling originating from the Pt atoms: This allows for the internal conversion between orbital currents and (detectable) spin currents, reducing the complexity of the required structures. A comprehensive low temperature and high magnetic field magnetotransport study of $PtSe_2$ is presented, with particular focus on the nature of the detected Shubnikov-de Haas oscillations. The oscillations are analytically described using an adapted Lifshitz-Kosevich formalism [3], enabling the extraction of key charge carrier characteristics through established fermiological approaches. Additionally, the interplay between the weak anti-localization, the Kondo effect [4] and the orbital magnetoresistance is investigated. These results position $PtSe_2$ as a platform for studying the orbital Hall effect and provides a detailed charge carrier characterization that informs the design of prospective spintronic and orbitronic devices.

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Probing the electronic structure at the boundary of topological insulators in the Bi_2Se_3 family by combined scanning tunneling and atomic force microscopy

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We develop a numerical scheme for the calculation of tunneling current I and differential conductance dI/dV of metal- and CO-terminated STM tips on the topological insulators Bi_2Se_3, Bi_2Te_2Se as well as Bi_2Te_3, and find excellent agreement with experiment. The calculation is an application of Chen's derivative rule, whereby the Bloch functions are obtained from Wannier-interpolated tight-binding Hamiltonians and maximally localized Wannier functions from first-principle DFT+GW calculations. We observe signatures of the topological boundary modes, their hybridization with bulk bands, Van Hove singularities of the bulk bands, and characterize the orbital character of these electronic modes using the high spatial resolution of STM and AFM. Bare DFT calculations are insufficient to explain the experimental data, which are instead accurately reproduced by many-body-corrected GW calculations. In future experiments we will leverage the atomic resolution of STM and AFM to investigate ring states. These electronic states arise at atomic-scale perturbations on topological insulators and are closely linked to nontrivial bulk topology and the non-existence of exponentially localized Wannier functions for these materials.

µSR study of superconducting nonsymmorphic nodal line semimetal $PtPb_3Bi$

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The concurrence of non-trivial band structure and superconductivity can host a novel phase called topological superconductivity [1]. A typical host of non-trivial band structures is topological semimetals, a class of gapless electronic phases showing topologically stable intersections of energy bands [2]. Crystalline symmetries, like nonsymmorphic symmetry, can play a pivotal role in influencing the band crossing along a line or loop [3]. The nonsymmorphic symmetry is responsible for symmetry-enforced band crossing that is impervious against hybridizations and disorders [4]. The nonsymmorphic materials have offered a reliable platform for topological superconductivity but have not been explored much [5].

I will present my recent work on the detailed investigation of the superconducting ground state properties of a new nonsymmorphic $PtPb_3Bi$ compound with tetragonal structure (space group $P4_2/mnm$, No. 136, point group D_{4h}). The superconducting and normal state properties were studied through heat capacity, electrical resistivity, magnetization, and muon spin rotation and relaxation (µSR) techniques. Our findings suggest that $PtPb_3Bi$ is an isotropic, nodeless s-wave superconductor, preserving time-reversal symmetry and exhibiting moderate electron-phonon coupling.

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[Classical Fracton Spin Liquid on the Octochlore Lattice]

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For nearly three decades, research in frustrated magnetism in three dimensions (3D) has prominently centered on the pyrochlore geometry of corner-sharing tetrahedra and the classical spin liquid (CSL) known as spin ice. We propose that a lattice of corner-sharing octahedra, octochlore lattice, may provide a next-generation platform for 3D frustrated magnetism with realizations in anti-perovskites and certain potassium-fluoride compounds with magnetic rare-earth ions. We study the phase diagram of Ising spins on the octochlore lattice with first- and second-neighbor interactions within each octahedron. In addition to a spin ice CSL [1], we identify a novel fracton CSL with excitations restricted to move on one-dimensional lines, which is a classical U(1) analog of the celebrated X-cube model [2] of fracton topological order. We characterize this fracton liquid from multiple perspectives—via its flat bands with nodal line touchings; as a condensate of spinon bound states; as a cage-net liquid; as a foliated fracton phase of intersecting spin vorticity models; and as a bionic spin liquid of intersecting square ice sheets. This work paves the way for the potential realization of fracton CSLs in real materials.

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Theory for optical control of correlated states in moiré transition metal dichalcogenide heterostructures

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In recent years, moiré transition metal dichalcogenide (TMD) heterostructures have emerged as highly versatile platforms for investigating phases and phenomena of strongly correlated electrons on emergent lattice scales. However, experimental characterization of the precise nature of some interaction-driven long-range ordered states and their excitations has remained a challenge. Given strong light-matter couplings and valley selection rules in TMD materials, ultrafast optical methods may constitute a promising avenue for probing and controlling these states and their collective modes.

In this work, we develop a theoretical framework to describe the coherent light-driven dynamics of type-II moiré TMD heterobilayers under circularly polarized laser irradiation. We construct a moiré-Floquet Hamiltonian for the electronic states under periodic driving. In the off-resonant regime, we find that the moiré valence band flattens due to hybridization with the photon-dressed conduction band and derive an effective low-energy model for the Floquet valence band. To study the impact of the optical driving on ordered states within the moiré valence band, and their collective modes, we incorporate electron-electron interaction via a self-consistent Hartree-Fock approach.

Hexagonal Boron Nitride on Molten and Single-Crystal Copper: Experimental and Computational Insights into Atomic Structure and Interfacial Interactions

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Two-dimensional materials (2DMs) like graphene and hexagonal boron nitride (h-BN) are essential for advancing nanoelectronics. However, the growth kinetics and interfacial interactions of 2DMs with substrates, especially comparing liquid and solid metal catalysts, remain incompletely understood. This study investigates the fundamental mechanisms of 2DM bonding and adsorption on molten copper (a liquid metal catalyst, LMCat) and its solidified single-crystal form, focusing on the quasi-metallic graphene and dielectric h-BN. Building on previous work with graphene CVD growth on LMCats [1], we synthesized h-BN on both liquid and solid copper, exploiting their atomically smooth, defect-free surfaces. In situ synchrotron-based X-ray Reflectometry (XRR) and Grazing Incidence Diffraction (GID) enabled atomic-scale structural characterization, supported by ex situ XPS, SEM, and Raman spectroscopy. To further interpret experimental results, we used machine-learning-assisted molecular dynamics simulations [2], achieving excellent agreement with measured h-BN adsorption heights, differing by less than 0.1 Å. The findings reveal that h-BN exhibits distinct interfacial behavior compared to graphene, driven by its dielectric nature. This comparison highlights the critical role of substrate phase and material properties in 2DM growth. Our results offer new insights to guide the controlled synthesis of 2DMs for nanoelectronics and optoelectronic applications.

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Topological Photovoltaics

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Abstract (max 200 words)

With increasing interest in the bulk photovoltaic effect in non-centrosymmetric as an alternative to traditional solar cells, there has been development in linking the nonlinear optical effects to the topology and quantum geometry of bands, which in particular crystallizes in terms of the shift current due to positional shifts in the electron wavefunction. This poster aims to introduce the BPVE and show how connections to topology arise naturally, and how they affect the phenomenology of the these “topological solar cells”.

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Acknowledgments

Spin and orbital Hall effects in Weyl semimetals

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In this paper we aim to understand the essential differences between the emergence of spin and orbital Hall effects in Weyl semimetals, paying particular attention to the role of magnetism. Firstly, we show that the recently proposed model for Weyl altermagnets [1] can display the spin Hall effect due to the distinct spin sublattices, overcoming the necessity of spin-orbit interaction. In this context, the latter is essential to obtain a nonzero orbital Hall effect. We then compare the transport properties of Weyl altermagnets with those of the well-known magnetic Weyl semimetal $Co_3Sn_2S_2$[2] and the nonmagnetic Weyl semimetal TaAs.

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Operator spreading in random circuits with symmetry

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Abstract

We investigate operator spreading and information scrambling in random quantum circuits with gates drawn from orthogonal-invariant ensembles. Unlike the unitary case, a Markovian description of the evolution emerges only after an appropriate projection. The ensemble-averaged Pauli-string weights relax not to a binary distribution, but to a ternary-valued structure, with a well-defined relaxation timescale only when the local Hilbert space dimension is the power of 2. Additionally, the domain wall separating trivial and scrambled regions acquires a finite width even when gates are Haar-distributed within the orthogonal group, reflecting the effect of symmetry constraints. Most importantly, we uncover a fundamental difference between the **special orthogonal ensemble** and the **orthogonal ensemble with negative determinant** in even dimensions. For the special orthogonal case, the butterfly velocity is bounded below by zero (trivial circuit) and above by the Haar measure. In contrast, for the orthogonal ensemble with negative determinant, the lower bound of the buttefly velocity is strictly positive and **independent** of the ensemble's probability distribution. Moreover, in this case, the Haar measure does **not** set the upper bound, which is also **independent** of the ensemble's probability distribution. These findings reveal qualitatively distinct scrambling dynamics in symmetric random circuits.

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