



The Book of Abstracts

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**Innovations in Understanding Complex Systems:
The Role of Spins, Disorder and Topology**

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Saddle-node bifurcations in solid state systems

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Abstract

The saddle-node bifurcation, or fold catastrophe, is a mechanism to drive singular transitions in non-linear systems that are simultaneously critical and abrupt. I will discuss three solid-state manifestations of this criticality: spinodal instabilities in metal-insulator transitions, charge density wave depinning, and electric field-induced thermal runaway in Mott insulators.

Beyond physics, saddle node bifurcations model "tipping points" in diverse complex systems, from human physiology to climate. It is believed that the critical singularity at the tipping point may yield early warning signs for the impending catastrophe. These include critical slowing down and large variance of fluctuations close to the tipping point. I will highlight our observations of these early warning signs.





Quantum oscillations in the magnetization and density of states of non-interacting and interacting insulators

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Abstract

The Fermi surface, the defining characteristic of metals, leads to oscillatory behavior of various observables as a function of the inverse magnetic field. It was thus a great surprise when such oscillations were seen in insulators without any Fermi surface, like in Kondo insulators. I will first briefly discuss a general theory [1] of quantum oscillations (QOs) in non-interacting hybridization-gap insulator and show that it exhibits distinct frequencies for Shubnikov deHass (SdH) and deHass-van Alphen (dHvA) oscillations for low-energy density of states and magnetization oscillations, respectively, unlike in a metal. Kondo insulators are, however, strongly correlated systems where the interaction effects cannot be a priori ignored. We generalize the periodic Anderson model to a solvable Sachdev-Ye-Kitaev (SYK)-like interactions for the f-electrons and study the effects of interactions on QOs in Kondo insulators. We find that while the QO frequencies remain almost unaffected by interactions, there are striking differences between SdH and dHvA oscillations, with the SdH amplitude strongly enhanced due to the renormalization of the effective gap. We also present an asymptotic low-temperature analysis to complement and analytically understand our numerical results.

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Quantum Hall Josephson junctions: overview and some recent theoretical results

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Abstract





Graphene-Based Epitaxial 2D Heterosystems: Harnessing Proximity Coupling for Emergent Quantum Phenomena

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Analytics of Solid Surfaces, Nanostructures and Quantum Materials

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Abstract

Two-dimensional (2D) materials and their heterostructures lie at the heart of next-generation quantum materials research. Among the many fascinating phenomena they enable, proximity coupling stands out as a key mechanism for realizing emergent and tunable functionalities. Epitaxial graphene (EG) grown on SiC(0001) represents a prototypical 2D electron gas system, renowned for its exceptional structural quality and versatile functionalization capabilities—both at its vacuum interface and buried interface sites. These characteristics make EG an ideal platform for probing and engineering proximity effects. Through targeted adsorption and intercalation strategies, diverse electronic and spin textures can be achieved—ranging from extreme doping levels and enhanced spin–orbit coupling to the emergence of interface states and mini-bands induced by zone folding. The controlled evolution from Dirac-like linear dispersion to flat-band behavior in EG, as well as its coupling to other 2D electron gases (2DEGs), provides a unique route to explore strong electronic correlations and mesoscopic quantum phenomena in epitaxial 2D heterosystems. In this presentation, I will highlight recent experimental advances involving the adsorption and intercalation of heavy elements such as Pb and Sn, showcasing how these approaches can be used to fine-tune graphene's properties and unlock new regimes of proximity-driven behavior.





Harnessing Topological Quantum Materials for Energy-Efficient Magnetic Memories

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Abstract

Modern computers rely on moving electrons to process information, a process that generates significant heat and limits device speed. A promising alternative is spintronics, which uses the spin of electrons instead of just their charge. A major goal in this field is to develop energy-efficient Spin-Orbit Torque (SOT) memories. However, current SOT technology has a bottleneck: it usually requires an external magnetic field to function, making devices bulky and difficult to scale down. In this talk, I will discuss how we can overcome this limitation using Mn_3Sn , a unique quantum material. By growing high-quality thin films of Mn_3Sn , we show that out-of-plane spin current is generated in this material due to its intrinsic bulk property. We further demonstrate that this effect allows us to switch magnetic data bits without an external magnetic field. Our results provide a clear roadmap for using quantum materials to build "field-free" memory chips that are faster, smaller, and more energy-efficient than current technology. I will also discuss our work in other quantum materials, including some 2D materials, where we observe unconventional SOT for memory applications.





Dynamic Heterogeneity and Kinetic Arrest in Disordered Magnetic and Non-Magnetic Colloids

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Abstract

We investigate and compare a range of indicators for glassiness in monodisperse magnetic and non-magnetic soft-sphere fluids at low temperatures with a view to exploring the effect of the magnetic moment. We perform extensive molecular dynamics simulations using the Stockmayer model for magnetic fluids and a pure Lennard-Jones interaction for the nonmagnetic case. Our investigations involve quenching experiments, in which both systems are rapidly cooled to temperatures well below their freezing points. Although the Lennard-Jones fluid forms compact aggregates, the inclusion of dipolar interactions promotes the development of branched and open morphologies. After characterizing the static properties of the resulting frozen structures, we focus on the dynamics, which, along with other observables, is defined by the behavior of the self-part of the van Hove function, that is, the probability that a particle has moved a distance Δ at time t . It exhibits a non-Gaussian behavior in both fluids, providing a signature of dynamic heterogeneities and glassiness. This behavior is characteristic of systems with immobile particles vibrating within cages and mobile particles, i.e., a separation of time scales between different relevant dynamic processes. The function exhibits a power-law tail in the Stockmayer fluid, whereas the Lennard-Jones system shows an exponential tail. These findings provide essential insights into the relaxation mechanisms pertinent to magnetic fluids, facilitating a deeper understanding of magnetically responsive colloidal systems.

Collaborations

- (1) Prof. Varsha Banerjee, Department of Physics, IIT Delhi
- (2) Mr. Lambert Münster and Prof. Martin Weigel, Institute of Physics, TU Chemnitz





Chirality-Induced Spin Selectivity: Spin-Polarized Transport at Chiral Molecular Interfaces

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Abstract

Chirality-induced spin selectivity (CISS) has emerged as a robust and surprising phenomenon in molecular-scale transport, revealing a direct link between structural chirality, spin-orbit interactions, and non-equilibrium spin polarization in the absence of conventional magnetic order: When electrons traverse chiral molecular layers, the transmitted current can acquire a pronounced spin polarization, placing CISS at the intersection of molecular electronics, spin physics, and interface-driven transport phenomena.

In this talk, I will introduce the fundamental concepts underlying the CISS effect, discussing its experimental manifestations, symmetry aspects, and the current status of theoretical interpretations. Particular emphasis will be placed on the interfacial nature of CISS, where molecular dipoles, local electric fields, and spin-orbit coupling at hybrid organic-inorganic junctions play a central role in generating spin-polarized currents.

As an experimental case study, I will present low-temperature STM and STS investigations of chiral molecular layers integrated into a GMR-like Au/Co/Au/Molecules junction geometry. Magnetization-dependent transport signals are observed upon electron transmission through the chiral molecules, providing direct evidence for CISS-induced spin polarization. Complementary magnetic-field-dependent feedback measurements reveal reproducible height shifts correlated with the magnetic state of the ferromagnetic layer, which are absent in achiral reference systems.

A simple model considering the magnetoresistance in series to the tunneling resistance manages to explain the data qualitatively. But for a good quantitative match more considerations like spin-dependent densities of states or interfacial effects need to be made. In combination with forthcoming electronic-structure input, this establishes the experimental foundation for a consistent determination of the CISS-induced magnetoresistance in chiral molecules.





Anti-Klein Tunneling in 2D Topological Insulators

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Abstract

Dirac electrons on the surface of three-dimensional topological insulators are expected to exhibit Klein tunneling, rendering them resistant to electrostatic confinement and backscattering[1]. In this talk, I will present experimental evidence for quantum confinement and anti-Klein tunneling behavior in exfoliated topological insulator thin flakes, revealed through atomically resolved scanning tunneling spectroscopy. By developing a controlled mechanical exfoliation technique that yields pristine ultrathin layers, we directly image quantum well states (QWS) arising from confined Dirac electrons—an effect rarely observed due to their relativistic tunneling nature. The observed QWS are quantitatively described by the phase accumulation model and show excellent agreement with first-principles band-structure calculations. We further demonstrate that interlayer coupling tunes the Dirac subband dispersion and that these confined states remain robust against defect scattering. These findings [2] establish topological insulator thin films as a platform to engineer Dirac confinement, explore anti-Klein tunneling regimes, and realize tunable topological quantum devices.

Reference

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Disorder and Excitations in Active and Passive Systems

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Abstract

Quenched disorder has profound effects on phase transitions in and out of equilibrium. As examples illustrating the use of computer simulations for studying such systems with frozen-in impurities we first consider the old problem of spin glasses, where the addition of frustration to disorder leads to the destruction of long-range order and the occurrence of a frozen, locally ordered phase. We demonstrate that the nature of the spin-glass phase can be understood in terms of a new class of excitations that combine low energy with extensive sizes and fractal boundaries. At the other end of the spectrum, we study a strongly out-of-equilibrium polar fluid of microswimmers, where the presence of obstacles leads to a curious order-by-disorder phenomenon, where external noise is required to induce alignment of the particles - an effect that can be understood by a competition of length scales in the problem.





Phase Separation in Active Systems

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Abstract

We discuss the kinetics of phase separation or coarsening in active systems. These systems are intrinsically nonequilibrium and do not relax to equilibrium, unlike passive segregating systems. We study the so-called Active Model B⁺ or AMB⁺, which is a phenomenological model of active phase separation. This is obtained as a generalization of the well-known Model B, which is the paradigm for passive phase separation. We highlight several novel features introduced by activity in phase-separating systems.





Stochastic heat engines: active, effective equilibrium and optimization aspects

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Abstract





Flocking transition in an active Ising model in one dimension

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Abstract

We consider a one-dimensional lattice of Ising spins in which two values of each Ising spin represent left- and right-moving particles. In the non-motile limit, this model exhibits absorbing ferromagnetic states. When activity is introduced through biased motility, these absorbing states are destabilised, and the system instead undergoes a flocking order–disorder transition as the alignment strength is varied. A finite-size scaling analysis of physical quantities reveals a continuous transition with critical exponents satisfying the hyperscaling relation, providing quantitative evidence for the occurrence of an activity-induced phase transition in a one-dimensional system.

This work was done in collaboration with Narayan Dutt Sharma, Subroto Mukerjee and Sriram Ramaswamy.





Experimental Manifestations of Topological Superconductivity in $6R\text{-SnNbSe}_2$

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Abstract

The material realization of topological superconductivity accrues current relevance because of its potential usage as qubits in fault-tolerant quantum computation. Towards this end, two approaches have been prescribed; one is the proximitized s-wave superconductivity on spin helical states, and the other is to realize an intrinsic topological superconductor with odd-parity spin-triplet pairing. Analogous to a topological insulator, in a three-dimensional topological superconductor (TSC) the superconducting bulk gap of the interior coexists with gapless surface states. The quasiparticle excitations of these surface states are theorized as Majorana fermions, and the experimental manifestation of such an exotic field-theoretical perspective is considered an essential component for the characterization of TSC. In this talk we shall discuss such a possibility in superconducting $6R\text{-SnNbSe}_2$ by determining its order parameter symmetry from the temperature-dependent penetration depth measurements. In general, the promising route to realize such topological superconductors involves inducing superconductivity in systems lacking inversion symmetry. We report on the synthesis and detailed characterization of Sn-intercalated NbSe_2 that forms a new polytype, $6R\text{-SnNbSe}_2$. This compound crystallizes in the centrosymmetric space group $R\bar{3}m$. Structural, electronic, and magnetic measurements confirm the emergence of a superconducting phase with a transition temperature $T_c \approx 4$ K. Temperature-dependent magnetic penetration depth and superfluid density measurements down to 1.5 K were performed using the tunnel diode oscillator technique. The findings suggest the mixing of nodal and nodeless order parameter symmetry in $6R\text{-SnNbSe}_2$. Such results are surprising for a centrosymmetric superconductor but are consistent with theoretical predictions of topological nodal-line features in SnNbSe_2 . Thus, $6R\text{-SnNbSe}_2$ emerges as an interesting platform for exploring unconventional pairing mechanism. Our findings suggest the possibility of $p_x + ip_y$ type pairing symmetry in this transition metal dichalcogenide.

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Magneto-transport behavior of heterostructures of metallic ultra-thin film multilayers and van der Waals magnets hosting magnetic skyrmions

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Abstract

Dzyaloshinskii-Moriya interaction (DMI) between spins plays a major role in the formation of chiral magnetic texture in non-centrosymmetric bulk crystals. This was later exploited in sputter deposited multilayered thin film heterostructures of ferromagnets and heavy metals to obtain magnetic skyrmions at room temperatures. For any development of skyrmion based future spintronics devices, an in-depth understanding of electrical transport behavior in skyrmion hosting materials is a critical requirement. Although topological Hall effect was observed in several skyrmionics systems, recently there is a debate about the origin of the topological-like Hall effect in some other systems without any DMI. In this talk, I will discuss our recent results of topological-like Hall effect in heterostructures of ultra-thin film metallic multilayers. The results are compared with the evolution of magnetic skyrmions as a function of magnetic field as imaged by magnetic force microscopy. Additionally, we were also recently successful in tuning magnetic interactions in 2-dimensional van der Waals magnets. The results will be discussed in light of the stabilization of magnetic skyrmions in such 2-dimensional magnets.





Emergence of chiral phases in bent core liquid crystals

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Abstract

We study coarsening in achiral banana shaped bent-core liquid crystals by quenching them from high concentration polar smectic (SmX) phase to lower concentrations that favour the enigmatic twist-bend (TB) phase [1,2]. Our novel result is an intermediate splay-bend state prior to the asymptotic TB phase. The latter grows via the annihilation of beta lines that are analogous to string defects in the usual nematic liquid crystals [3]. Moving ahead, our observations and methodologies are relevant for a large class of chiral soft matter systems that are unraveling novel topological knots and their self-assembly [5,6].

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Nonequilibrium studies of the $d = 3$ Ising model at zero temperature: Domain growth and aging

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Abstract

The phase-ordering kinetics following a quench to zero temperature in the three-dimensional Ising model are considered. From theory, a power-law growth of domains of like spins with exponent $\alpha = 1/2$ is predicted. In contrast to quenches to non-zero temperature, including recent work, it was not possible to clearly observe this growth law when the quench temperature was set to zero. In an attempt to verify the prediction we run large-scale Monte Carlo simulations of lattice sizes up to $L = 2048$ and make a surprising discovery [1]. At late times domains show superdiffusive growth, i.e., $\alpha > 1/2$, which we show may be caused by sponge-like structures emerging at early times. Further, we study aging [2] in this process. In this model the two-time spin-spin autocorrelator is expected to obey dynamical scaling and to follow a power-law decay with exponent λ . Despite using much larger systems than have been studied before, we see no clear dynamical scaling in the autocorrelation function and the exponent λ effectively varies with time. While previous work indicated that the lower Fisher-Huse bound of $\lambda \geq d/2 = 1.5$ is violated in this model, the instantaneous exponents we obtain at late times do not disagree with this bound.

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Efficient cluster updates for spin glasses: A comparative study

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Abstract

In this work, we investigate efficient simulation algorithms for spinglass systems such as the Edwards-Anderson model, a disordered magnetic system characterized by competing ferromagnetic and antiferromagnetic interactions and a highly complex free-energy landscape. Such landscapes pose severe challenges for numerical simulation, as single-spin flip methods as well as generalized-ensemble approaches such as parallel tempering exhibit slow convergence to low-energy states. To alleviate this problem, a range of cluster updates has been proposed for simulations of frustrated systems. Focusing on two- and three-dimensional spin glasses, we aim to identify and benchmark algorithms that can significantly accelerate thermalization. By systematically comparing cluster-based and conventional methods, we assess their efficiency in reaching equilibrium and traversing rugged free-energy landscapes.

