Moiré domain-wall networks: a playground for correlated and topological phases

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We explore domain-wall networks in twisted bilayer graphene under an interlayer bias. In this talk, I will begin by introducing our bosonic model for interacting electrons in these networks [1-3]. The electron-electron interaction strength is tunable through sample design and gate voltages, which also control various correlation functions [1]. By including electron-phonon coupling, we obtain phase diagrams exhibiting density-wave and superconducting orders with electrically tunable phase transitions.

We then develop scattering operators to classify different processes in the network. Certain processes yield gapped bulk states with gapless edge modes [2], leading to (fractional) quantum anomalous Hall effects. We predict spectroscopic and transport signatures of these phases. The network models integrate concepts from the quantum anomalous Hall [2], quantum Hall [4], and quantum spin Hall [5] effects, demonstrating their broad applicability to topological and correlated systems.

If time permits, I will also discuss the formation of a two-dimensional spin helix in the presence of local magnetic moments [3], which exhibits magnon-induced singularities with observable features. These results establish the moiré domain-wall network as a versatile and electrically tunable platform for correlated electron phenomena.

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Keywords: Moiré bilayer systems, correlated electron systems, topological phases, fractional excitations, bosonization

Neutron Scattering Reveals Flow-Induced Structural Transformation and Orientational Alignment in Soft Condensed Matter

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The microstructural response of complex soft condensed matter aggregates to externally applied fields is tightly coupled to macroscopic properties such as stability, transport, and rheology. Because soft aggregates can access a wide spectrum of equilibrium and non-equilibrium morphologies, establishing quantitative links between field-driven structural change and material function remains essential for both industrial formulations and biological systems.

In this talk, I will briefly outline the fundamental principles of elastic neutron scattering for characterizing soft matter under controlled conditions, and I will present our recently developed analysis tools for extracting microstructural parameters and distortion directly from two-dimensional scattering patterns. Central to this effort is a spectral decomposition framework based on a real spherical harmonics expansion (RSHE), which enables reconstruction of local strain signatures and orientational distribution functions in a unified, quantitative manner.

As a case study, I will focus on rod-like micellar solutions under steady shear, where RSHE resolves the coupled evolution of micellar alignment and aggregation length. Using small-angle neutron scattering (SANS) together with rheological measurements on aqueous CTAB rod-like micelles in sodium-nitrate brine, we observe a pronounced increase in angular anisotropy in the 2D SANS patterns with increasing shear rate, in the absence of shear banding. RSHE analysis reveals simultaneous enhancement of flow alignment and a systematic decrease in the mean micellar contour length. The resulting scaling of mean contour length with shear rate is consistent with predictions from first-principles analytical theory and dissipative particle dynamics simulations. Collectively, these results provide direct experimental evidence for flow-induced alignment and scission in rod-like micelles, and they establish a general framework for interpreting shear-dependent microstructural transformations from 2D neutron scattering.

Keywords: soft condensed matter; flow-induced microstructure; orientational distribution function; rod-like micelles; small-angle neutron scattering; real spherical harmonics expansion

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Reliable communication over noisy quantum channels

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To protect information against quantum noise in communication, Alice at the transmitter first encodes information to be sent into large block codes; Bob then coherently decodes the noisy information at the receiver. The channel capacity theorem demonstrates that reliable communication is possible, as the code length approaches asymptotic infinity. A previous work [Nat. Commun. 7, 2016] analyzed finite-length codes for achieving a code rate close to the channel capacity. However, the required code length to achieve an ε error is of order O(1/ε^2), which is still quite challenging in practice for reliable communication with a small error.

In this talk, we show that the code length scales only logarithmically in ε, exponentially improving on the previous result. Moreover, the established error exponent is essentially optimal for all high rates. Our result extends to classical communication over any quantum channel with or without entanglement assistance.

This talk is based on [PRX Quantum, 4, 040330 (2023)] and [arXiv:2507.06232].

Keywords: N/A, N/A, N/A

Various effort in implementing quantum information processing under realistic considerations

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We will share the recent direction and progress in our research group, which mainly focus on implementation of quantum information processing under realistic considerations.

Keywords: quantum metrology, quantum computing, noise

Ghost Rotationally-Invariant Slave-Boson Approach to Correlated Quantum Materials

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Simulating the properties of correlated quantum materials from first principles remains a grand challenge in condensed matter physics and materials science. Conventional density functional theory (DFT) often fails to capture strong Coulomb correlations, leading to inaccurate predictions of electronic and structural properties. More advanced many-body techniques, such as dynamical mean-field theory (DMFT) and quantum Monte Carlo (QMC), offer improved accuracy but with higher computational costs, limiting their applicability to small systems. In this talk, I will introduce the DFT plus ghost-rotationally-invariant slave-boson (DFT+gRISB) method—also known as the ghost-Gutzwiller approximation [1–6]—which aims to balance computational efficiency with physical accuracy. I will review early applications of DFT+RISB to binary transition-metal oxides, demonstrating its success in benchmarking crystal structures against experiments [2], and then highlight recent advances enabled by DFT+gRISB that systematically improve upon previous RISB results for transition-metal oxides [4–6]. Finally, I will discuss emerging applications of gRISB, including its ability to capture structural distortion in SrMoO3, integrating with machine-learning techniques, and its extension to response-function calculations [7].

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Keywords: quantum materials, strongly correlated materials, ab initio simulation

Structural Quality, Not Quantity: Molecular Simulations of Protein Aggregation Dynamics

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Protein aggregation represents a rich example of self-organization and phase-transition–like behavior in biological systems.

While conventional views emphasize the quantity of aggregation—such as oligomer size or growth rate—as the dominant control parameter, our recent coarse-grained molecular dynamics simulations reveal that it is the quality of structural organization that governs the emergent kinetics and functional outcomes. I will present three representative systems illustrating this principle.

1. Aβ42 peptides: monomer diffusion on twisted fibril surfaces shows how geometric frustration and surface roughness modulate nucleation kinetics.

2. TDP-43 proline variants: changes in local sequence stiffness drive transitions between ordered and disordered oligomer states, resembling order–disorder transitions in polymer systems.

3. Cofilin oligomers: interface-specific disulfide bonding controls higher-order assembly, highlighting how chemical connectivity constrains mesoscale organization.

Together, these studies point to a unifying principle: the structural order parameter—rather than aggregate number—determines the fate of protein assembly and regulation. This perspective links molecular biophysics with nonequilibrium statistical mechanics, suggesting new routes to describe and control protein aggregation as a complex emergent process.

Keywords: Protein Aggregation, Cytoskeleton, Molecular Dynamics Simulation

Dynamics of a competitive rock-scissors-paper community under invasion

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The coexistence mystery, designated “the paradox of the plankton”, remains an open question in ecology. Under competitive Lotka-Volterra (CLV) model, modern coexistence theory (MCT) delineates the problem of coexistence between two competitors: two species coexist if their niche overlap is low enough to offset their relative fitness differences. May and Leonard (ML), using a CLV model, showed that three competitors whose competition dynamic is cyclic, like in the game of rock-scissors-paper (RSP), can stably coexist even when each pair cannot coexist in isolation. In this work, an extension of the ML model is used to study the effect of a single invader on the coexistence of a stable RSP community. Assuming the invader interacts with one, two or all three species among RSP, we analytically identify parameter regimes where invasion fails or succeeds. After successful invasion, and depending on the strength of competition between the invader and resident species, invader can either coexist with RSP or exclude at least one species from the triplet. We also identify parameter regimes where invader-RSP coexistence occurs via stable limit and/or heteroclinic cycles. Overall, our results show that the four-species CLV model can exhibit very rich dynamics ranging from limit cycles to multiple heteroclinic cycles to strange nonchaotic attractors. We further show that results from the ODE model remain consistent even when spatial stochasticity is added to the model.

Keywords: cyclic competition, invasion criterion, Lotka-Volterra model, species coexistence, heteroclinic cycles