

Supernova classification and host subtraction for DESI spectra

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The Dark Energy Spectroscopic Instrument (DESI) Transients Survey captures spectra of transients, such as supernovae and tidal disruption events. We identified supernova spectra taken by DESI in the past 18 months and classified them, finding mostly Type II and Type Ia. However, supernova spectra are often contaminated by their underlying galaxy. Using DESI's vast galaxy catalog, we identified supernovae for which DESI had spectra for their host galaxies, and used these host spectra to subtract away the galactic contamination. Removing galactic contamination reveals possible circumstellar medium lines which arise when the ejecta from a supernova interacts with the mass shed by the star before going supernova. Additionally, we utilized ZTF light curves to determine the phases of the supernovae which allows us to identify infant supernovae. Using these phases, we studied how supernovae evolve spectroscopically over time by measuring the pseudo-equivalent widths (pEWs) of key spectroscopic features. The pEWs also allowed further classification of Type Ia supernovae which could lead to better Type Ia supernovae models which would make them better standard candles.

Tensor compression for faster electron transport calculations

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Electron-electron limited transport properties are important for understanding collective electronic behavior in quantum materials. In particular, first-principles calculations of quantities such as electronic viscosity require accurate electron-electron scattering rates. These calculations are currently limited by the cost of evaluating and storing the screened electron-electron interaction, which is represented by a high-dimensional tensor that depends on several momentum and band indices. Compression methods have already been applied successfully to other large quantities in transport calculations, including electron-phonon matrix elements, where tensor-based approaches have reduced storage and interpolation costs. Here, we aim to apply a similar tensor compression strategy to the screened electron-electron interaction. The interaction data are stored in an HDF5 file with separate real and imaginary components, and a PyTorch data-loading pipeline has been developed to read small tensor blocks without loading the full dataset into memory. A preliminary low-rank model was also tested to verify the full workflow, including batching, GPU transfer, prediction, loss evaluation, and back-propagation. Although this initial model produced poor reconstruction accuracy, it confirmed that the computational pipeline is working. The next step is to implement a physics-consistent tensor hypercontraction model. The final goal is to achieve at least an order-of-magnitude reduction in memory while maintaining the accuracy of the original first-principles interaction tensor.

Solving the Navier-Stokes equation for electron fluids of finite geometries

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Electron hydrodynamics is a transport regime in which momentum-conserving electron-electron scattering dominates over momentum-relaxing scattering, allowing charge carriers to behave collectively as a viscous fluid. For a 2D material, it is required that $lee \ll W$ and $lee \ll l_{MR}$, where lee is the length scale of electron-electron interaction that conserves momentum, W the sample width, and l_{MR} the mean free path of momentum-relaxing scattering. This project aimed at developing a computational framework for simulating the regime in finite 2D materials. The model was built to first reproduce the results in graphene/hexagonal boron nitride (hBN) observed by Sulpizio *et al.* A steady-state Navier-Stokes equation containing Lorentz force was solved in OpenFOAM using parameters and boundary conditions inferred from the literature. The transverse Hall response was obtained from the

simulations, and the normalized curvature of Hall field was compared with the experimental values. The simulated values followed the published trend in the literature, with deviations ranging from 3.5% to 7.4% across the carrier densities considered. The result provided a benchmark for the approach, supporting the plan to extend to anisotropic materials.

Calculation and analysis of reduced density matrices for quantum period-finding and integer factorization

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Quantum period-finding (QPF) is essential to achieving quantum speed-ups to classically difficult problems. The study of the structure of exact and approximate 1-qubit reduced density matrices (1-RDMs) of quantum circuits has revealed a method of determining an unknown period via root-finding on classical machines. We have worked to determine the properties of and improve this algorithm. Simulating a circuit through 3-RDMs and using those to approximate the 1-RDMs in our root-finding algorithm allows for the discovery of periods of the form $(1, 3, 5, 7) \cdot 2^k$ in polynomial time. Testing several methods of approximation has also revealed an optimal approach: by leveraging the entanglement graph of a circuit, one may select which 3-RDMs to reduce into 1-RDMs via partial tracing with low additional cost. Further, we have rigorously demonstrated polynomial scaling of our algorithm with respect to the number of qubits and found the distribution of the number of attempts taken by our algorithm to factor large semiprimes.

How do rattlesnake rattles make sound?

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Rattlesnakes produce a characteristic broadband sound using their rattle, a chain of hollow, interlocking keratin shells. Although shake rate is known to modulate the acoustic signal behaviorally, how segment geometry shapes the underlying mechanical response remains poorly understood. We investigate how structural and actuation parameters influence the collision and vibrational dynamics of the chain by decomposing the problem into several stages. The shell geometry is parametrized, assembled into an interlocking chain, and simulated using the Level Set Discrete Element Method (LS-DEM), with the chain driven periodically at one end. These simulations provide the location, timing, and impulse of each collision. The collisions are then applied as impact loads to an individual shell in a finite-element model using COMSOL Structural Mechanics. The resulting vibration is well approximated through modal superposition, expressed as a sum over the impacts experienced by the shell and its vibrational modes. Finally, we use COMSOL Acoustics simulations to identify the leading modal contributions to the rattle sound and compare the simulated spectrum with the biological sound spectrum. By integrating tail-scale collision dynamics, shell-scale vibration, and acoustic propagation, this work provides a framework for understanding and designing bio-inspired interlocking structures with tunable vibrational and acoustic properties.

Chirality-induced effects on magnetism in helical nanowires and torus knots

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Nanoscale magnetic helices and knotted torus structures are promising candidates for future spintronic and nanomagnetic computing devices due to their inherent chirality and curvature-induced spin textures. However, a systematic study relating geometry (pitch, radius, and knot topology) to magnetic switching behavior has not yet been established. This work uses micromagnetic simulations in MuMax3 to perform angle-dependent hysteresis measurements on helices with varying pitch, radius, and number of turns, as well as knotted torus structures under in-plane and out-of-plane fields, characterizing how geometry influences coercivity, remanence, and magnetization reversal. Decreasing helix pitch produces more gradual magnetization switching, consistent with multiple magnetic domains forming along the helix, while coercivity depends strongly on field angle, with smaller-pitch helices showing lower coercivity near perpendicular angles but a pronounced spike near 75°, indicating significant anisotropy. The knotted structures show similarly angle-dependent

coercivity and remanence with a periodic pattern reflecting knot symmetry, suggesting topology-driven anisotropy could enable switching applications. In parallel, helices spanning a range of pitches and radii have been fabricated via Focused Electron Beam Ion Deposition (FEBID) and sputter deposition. Future work includes Lorentz TEM imaging of fabricated helices to compare against simulations, alongside continued simulation of knotted structures.

Fully-coupled oscillations of perturbed Kerr-Newman black holes

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Perturbed black holes undergo a characteristic ringdown process to return to their equilibrium state, emitting a discrete spectrum of quasinormal modes (QNMs) dependent on the geometry of their spacetime. We investigate the free gravito-electromagnetic response of Kerr-Newman (KN) black holes, which can be described by a set of two coupled gauge-invariant partial differential equations. These equations lack the separability available in the Kerr and Reissner-Nordström (RN) limits. We construct a two-dimensional Chebyshev pseudospectral solver that imposes ingoing-horizon, outgoing-asymptotic, and regular-polar boundary conditions. QNM frequencies are obtained by minimizing the relative smallest singular value of the discretized coupled operator, while the associated singular vectors provide the mode eigenfunctions. The solver is validated using convergence and boundary-residual tests, and by recovering established Kerr and RN spectra, as well as published KN mode sequences. Using the coupled eigenfunctions, we reconstruct the gravitational and electromagnetic radiation variables Ψ_{-2} and Ψ_{-1} , generate free ringdown waveforms and angular emission patterns, and examine how spin and charge can modify the continuity of the spectrum of KN QNMs. This framework provides a route towards a KN Green's function and, ultimately, sourced waveforms for compact objects interacting with charged, rotating black holes.

Restrictions on non-Clifford fault tolerance and ruling out beyond-SQL quantum metrology

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Quantum metrology promises a quadratic speedup over the standard quantum limit (SQL), but signal-aligned noise is expected to preclude this advantage in realistic settings. A potential route around known no-go results is to encode the sensors in a quantum code where the physical signal acts transversally as a logical gate. Understanding restrictions on transversal non-Clifford gates is therefore central to both quantum metrology and fault-tolerant quantum computation. Here, we prove such restrictions and apply them to transversal sensing. For any stabilizer code of distance $d \geq 3$ supporting a transversal logical action in level D of the Clifford hierarchy, every stabilizer generating set must contain a check of weight at least 2^D . Moreover, any r -level concatenated realization satisfies $r \leq \lfloor \log_2 n/D \rfloor$, forcing $r=1$ and ruling out concatenation when applied to beyond-SQL metrology. We then show that transversal single-qubit rotations by a small angle θ can only induce a nontrivial logical action on an n -qubit code if its checks include irreducible stabilizers of weight $\Omega(1/(n|\theta|^2))$. Here, many single-qubit errors commute with every stabilizer or logical Pauli below this weight and are only detected by a high-weight check, so their syndromes cannot be fault-tolerantly reconstructed from low-weight normalizer measurements. Since beyond-SQL transversal sensing requires $|\theta| = o(n^{-1/2})$, the weight of checks required for syndrome extraction diverges with n . Finally, we prove a broader metrological no-go theorem that avoids the assumptions of the quantum Cramér-Rao bound: constant-strength signal-aligned noise rules out any asymptotic advantage over the SQL in AC or DC sensing, even with biased estimators, nonstabilizer or approximate encodings, quantum memory, intermediate measurements, or adaptive control.