

Topological phase transitions in three-dimensional quantum spin liquids with neural quantum states

Sanzhar Bissenali

Mentors: Norman Yao, Marco Bernardi, and Sajant Anand

Neural quantum states (NQS) offer a variational route to strongly correlated phases of matter, but optimizing them in topologically ordered regimes remains difficult. We extend the approximately-symmetric neural network ansatz, previously developed in two dimensions, to the three-dimensional toric code in a uniform magnetic field. While symmetry-unaware convolutional networks get stuck in local minima, our ansatz converges to quantum Monte Carlo (QMC) ground-state energies with relative errors of order 10^{-4} - 10^{-3} for systems of up to 882 spins. Using the Fredenhagen-Marcus string order parameter and the Rényi entropy, we map the topological-to-trivial phase diagram in the sign-problem-free (h_x, h_z) plane and find good agreement with prior QMC predictions. The same architecture applies directly to the sign-problem-full regimes (the h_y field and the fermionic toric code) where unbiased QMC is unavailable.

Cooling a many-body spin system in diamond using optically reset NV centers

Thuwaragesh Jayachandran

Mentors: Norman Yao, Andrei Faraon, Che Liu, and Haopu Yang

A major limitation of solid state quantum simulation platforms is that an interacting many-body system generally cannot be initialized in a low energy state. The natural starting point is an effectively infinite temperature state. We demonstrate cooling of an interacting ensemble of P1 centers in diamond, a many-body spin system, using nitrogen vacancy (NV) centers as a controllable bath. The NV is dressed by a spin-locking type microwave drive which tunes its effective energy splitting into resonance with the few MHz P1-P1 dipolar interaction scale. Resonant flip-flops then transfer energy from the P1 ensemble to the NV, and optical reset of the NV carries that energy out of the system. The cooling effect is probed by the difference in the spin-locking relaxation time scales which are limited by the noise generated from the P1 ensemble at different cooled temperatures. These results establish bath based cooling as a practical route to preparing low entropy states in interacting dipolar spin systems.

SLAC ATLAS ITk pixel testing and beam-induced background in the FCC

Margaux H. Wong

Mentors: Charles Young and Harvey B. Newman

Over the next five years, the Large Hadron Collider (LHC) at CERN will be upgraded to increase the luminosity and thus probability of observing rare interactions such as Higgs boson self-coupling. SLAC is assembling the Inner System of the new ATLAS Inner Tracker to be shipped to CERN in final form. During module reception, pixel modules were visually inspected and output data integrity, front-end chip functionality, sensor longevity, and bump bond connectivity were tested. Modules withstanding transit conditions during final shipment undamaged is critical. Thus, a test was designed to study module shock tolerances with results determining shipping procedures. The Drop Test setup was optimized to produce consistent acceleration over multiple iterations simulating measured shipping parameters. Modules were dropped with an increasing drop count and subsequent performance tested. Separately, theoretical work was performed on the Future Circular Collider, a possible successor to the LHC designed to enable new studies such as top quark and flavor physics research. The impact of undesired beam-induced background particles on the detector was simulated with a particle gun. Particle trajectories were reconstructed for different amounts of background with the ultimate goal of determining track parameter resolution thresholds to inform future designs and necessary tolerances.

ATLAS ITk pixel testing and laser characterization of the NAPA-p2 monolithic active pixel sensor

Emily J. Wu

Mentors: Charles Young, Harvey B. Newman, and Caterina Vernieri

Sensors for high energy physics experiments must meet benchmarks for sufficient spatial resolution and radiation hardness while maintaining low material and power budget. As the LHC upgrades to HL-LHC, significant increases in pp interactions and instantaneous luminosity will demand detector improvements. ATLAS will replace its inner detector with an all-silicon Inner Tracker (ITk), featuring an inner pixel detector comprised of hybrid pixel modules. Hybrid pixel modules are composed of separate front-end CMOS chips and passive, high-resistivity silicon sensors joined through bump-bonding, with a flexible PCB serving as the module connection interface. ITk will face the highest radiation fluence and pileup in the detector system, necessitating quality control (QC) to ensure performance within specifications. We perform electrical QC tests to evaluate data link quality, functionality of analog and digital electronics, equivalent noise charge levels, sensor dynamic range via leakage current and breakdown voltage, and bump bond connectivity. This characterization provides a systematic approach for validating detector modules.

While ITk employs traditional hybrid pixel modules, development of monolithic active pixel sensors (MAPS) is ongoing. In MAPS, the pixel sensor and front-end readout chip are integrated on a common silicon substrate and can be fabricated using standard CMOS processes, offering benefits in noise, cost, material budget, and power efficiency. Ongoing analysis of the 65nm NAPA-p2 MAPS prototype seeks to characterize pixel efficiency, time walk, and jitter. A 1080nm pulsed laser is delivered through a fiber and focused on a selected pixel to generate signal charge. These measurements will inform optimization of MAPS and future silicon pixel detectors for targeted implementation in $e+e-$ colliders.

Classical quantum field theory: A field-ontological interacting many-worlds interpretation

Blake W. Hawkins

Mentor: Charles T. Sebens

Quantum theory is our most accurate mathematical framework for describing fundamental physics, but the ontology and structure of physical reality it describes remains a matter of interpretation. In the non-relativistic regime, Newtonian Quantum Mechanics (NQM) offers a metaphysically appealing interacting many-worlds interpretation of quantum mechanics, in which quantum effects arise from interworld interactions between classical point particles. The wavefunction is eliminated from the fundamental ontology and Born-rule probabilities can be naturally understood in terms of self-locating uncertainty. Here, we extend the core principles of NQM to relativistic quantum field theory, constructing a field-ontological interacting many-worlds interpretation in which quantum effects arise from interworld interactions between classical field configurations. Among the implications of CQFT, particular attention is given to the treatment of energy.

Super-resolution for high pressure quantum sensing with NVs in round-table diamond anvil cells

Ahaan Shetty

Mentors: Norman Yao, Thomas F. Rosenbaum, and Srinivas Mandyam

This project develops a super-resolution optical platform for imaging superconductors under extreme pressure. Diamond anvil cells (DACs) generate high pressures by compressing a sample between opposing diamonds. Nitrogen-vacancy centers embedded near the diamond surface serve as quantum sensors of magnetic fields, temperature, and strain. However, conventional diamond anvils introduce strong optical aberrations through refraction at the air-diamond interface, limiting spatial resolution to several micrometers despite a diffraction limit of a few hundred nanometers. To address this limitation, we employ Diamond Anvils with a Round Table (DART), whose spherical upper surface reduces refraction and aberration by allowing light to enter normal to the interface. Confocal

microscopy and initial benchmarking measurements demonstrate improved imaging performance, with resolution approaching the diffraction limit. A wide-field microscope is used to implement structured illumination microscopy (SIM) to improve resolution by approximately a factor of two. We image magnetic vortices in the cuprate superconductor Yttrium barium copper oxide (YBCO), which we use to characterize London penetration depth and relationship with superfluid stiffness. This provides an exciting avenue to probe new physics, as the first pressure-tuned study of superconductors with such high spatial resolution.

Quantum calorimetry: NV-center-based AC thermometry towards megabar pressures

Amith Varambally

Mentors: Norman Yao, David Hsieh, and Srinivas Mandyam

Pressure is a powerful tuning parameter for phase transitions, but above roughly 10 GPa heat capacity becomes impractical to measure. Such pressures are typically reached in a diamond anvil cell, whose sample chamber spans only a few tens of microns. Conventional calorimetry wires a heater and thermometer directly to the sample, and that hardware neither fits nor survives compression. Optical techniques avoid the wiring but yield only the ratio of thermal conductivity to heat capacity, in which a transition that raises both quantities can go undetected. This project addresses that limitation by replacing the thermometer itself. Nitrogen-vacancy (NV) centers in diamond exhibit a spin resonance near 2.87 GHz whose frequency shifts with temperature at approximately -70 kHz/K. Nanodiamonds hosting these centers can be deposited directly onto a sample prior to loading and are expected to remain functional towards megabar pressures. Interferometric pulse sequences adapted from NV magnetometry resolve kilohertz-to-megahertz oscillations of this resonance, the range required for AC calorimetry. We modulate a heating laser and record the resulting oscillation of the NV resonance. Its amplitude determines the temperature oscillation, and therefore the heat capacity. Its phase lag relative to the drive determines the thermal conductivity, so that the two quantities are obtained independently rather than as a ratio. Over the summer we constructed the confocal microscope for this measurement and implemented the pulse sequences that perform the thermometry. These include a variant of the Ramsey sequence in which the magnetic contribution to the accumulated spin phase cancels while the thermal contribution is retained. As initial demonstrations we target the antiferromagnetic-to-paramagnetic transition of chromium near 311 K. We then map the heat capacity across the $\alpha \rightarrow \epsilon$ structural transition of iron from 0 to 20 GPa, alongside magnetization, thermal conductivity, and spin relaxation on the same platform. Together these establish a route to heat-capacity measurement in a regime where it has been inaccessible, and one that extends in principle to megabar pressures.

Constraint of coronal temperature and properties of local low-luminosity active galactic nuclei

Zoe K. Granadoz

Mentors: Fiona A. Harrison and Xiurui Zhao

More than 80% of X-rays in the extragalactic universe are found to be sourced from active galactic nuclei (AGN). The X-ray emission from AGN is thought to originate from a compact, hot corona surrounding the central supermassive black hole. Despite its fundamental role in powering the X-ray emissions, the physical nature of the corona remains poorly understood. I present a study of the physical properties of AGN coronae using a well-defined sample of local, low-luminosity AGN with high-quality X-ray data. By applying state-of-the-art physical models, we obtain robust measurements of key coronal properties, including the electron temperature and optical depth. We compare these results with those derived for distant, high-luminosity AGN, enabling the first systematic investigation of coronal properties across a broad range of AGN luminosities. I will also discuss the statistical techniques used to derive reliable population constraints and highlight the implications of our results for the physical origin of AGN coronae and for future X-ray observing strategies.

Symmetry-preserving reconstruction of Higgs boson pairs and a controlled test of pretrained jet representations

Idil Doga Turkmen

Mentor: Harvey B. Newman

Higgs boson pair production directly probes the Higgs self-coupling and the Standard Model Higgs potential. I study events where both Higgs bosons decay to bottom-quark pairs, producing four bottom quarks ($HH \rightarrow 4b$), where large backgrounds and ambiguous jet pairing make reconstruction difficult. I compare cut-based selections, boosted decision trees, dense neural networks, Lorentz Boost Networks that learn from particle four-momenta, and SPA-Net, an attention network that reconstructs the two Higgs bosons regardless of jet order. In the initial simulated study, the mass-aware boosted decision tree performed best; on a larger sample, SPA-Net achieved strong signal-background separation (AUC 0.969) together with Higgs reconstruction. I extend earlier $HH \rightarrow 4b$ studies by testing whether a pretrained Particle Transformer (ParT), which learns from particles inside each jet, adds useful information to SPA-Net. Direct feature addition hurts performance, while controlled integration removes this harm but yields no practically meaningful gain, showing that pretrained information must match the target analysis. CMS projects evidence-level HH sensitivity of about 3.5σ with 2 ab^{-1} and 4.2σ with 3 ab^{-1} at the High-Luminosity LHC, approaching the 5σ observation threshold. Extending these methods to boosted Higgs decays could increase sensitivity to heavy resonances and other new processes producing Higgs bosons. <https://github.com/idildogaturkmen/hh4b-surf>

Observer phases in dS_3 quantum gravity

Damian R. Musk

Mentors: Joseph D. Lykken and Maria Spiropulu

We study complex phases in the semiclassical partition function of three-dimensional de Sitter gravity. We first derive the one-loop graviton contribution on the three-sphere and on lens spaces, retaining all effects from gauge fixing, conformal and zero modes, conformal Killing vectors, contour choices, and normalization. We then reassess the proposed equivalence between metric and Chern-Simons formulations, with particular attention to overlooked phase and measure factors. Finally, we translate recent observer-based interpretations of gravitational phases into Chern-Simons language, testing whether observers are represented by Wilson lines or related defects. This provides a gauge-theoretic interpretation of phases in de Sitter quantum gravity.

Holography in the parafermion SYK

Madeline H. Mooney

Mentors: Maria Spiropulu and Joseph D. Lykken

We study a generalization of the Sachdev-Ye-Kitaev (SYK) model. Replacing Majorana fermions with parafermions, fractional statistics and a global D_n symmetry are introduced whilst preserving the SYK's all-to-all random interactions. As the Majorana SYK possesses a Jackiw-Teitelboim (JT) gravity dual, we investigate whether analogous holographic behavior is retained in the parafermion SYK. Presenting two models, we show one to lack a spin-glass phase---an important ansatz in holography. For the other model, we take the double-scaled limit---here reformulating traditional chord diagrams into a gas ensemble---and locally derive a Schwarzian action. The chord gas also admits (regardless of any specific model) a $\text{Diff}_+(S^1)/\text{PSL}(2, \mathbb{R})$ structure consistent with the boundary configuration space of JT gravity.