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Student-Faculty Programs

# Session W Abstracts

### Growth and transport characterization of thin β-FeSe via confined flux synthesis

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The realization of fault-tolerant quantum computing relies heavily on materials capable of hosting topologically protected quantum states. Currently, researchers are particularly interested in iron-based superconductors. Specifically, thin β-FeSe has emerged as an ideal platform due to its highly tunable critical temperatures (Tc) and its potential to host Majorana zero modes. However, current growth techniques (e.g. MBE, CVD, ALD, etc.) fail to fabricate high quality thin crystals with smooth surfaces, large area, and low stoichiometric impurities. We employ a NaCl/KCl bulk flux technique confined between mica layers to fabricate large area, high quality thin films of β-FeSe. Using structural and electronic characterization (e.g. Raman spectroscopy, transport, X-Ray Diffraction, and Atomic Force Microscope) we aim to confirm surface uniformity, elemental composition, and high temperature superconductivity.

### Uniaxial strain tuning of Hall response in EuAuP

Mingjun Fan
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EuAuP exhibits a giant Hall effect at zero magnetic field despite vanishingly small net magnetization, which has been proposed to originate from a real-space topological spin texture. This project investigates whether uniaxial strain can tune this response. Crystals were polished to 50-100 µm and mounted on piezoelectric strain cells. Longitudinal and transverse voltages were measured from 1.7 to 10 K with a magnetic field applied along the c axis and uniaxial strain of up to ±0.6% (nominal) within the ab plane. In the first sample, the Hall signal varied most strongly at 1.7 K, changing linearly with strain; a linear extrapolation predicted a sign reversal of the Hall signal near -1.3% strain. Subsequent samples exhibited comparable linear tuning only at 5 K, while the response at other temperatures was substantially weaker. The next step is to establish data reproducibility and clarify temperature dependence before extending the study to larger strain amplitudes and different strain orientations within the ab plane.

### Time-resolved domain dynamics of microwave-driven quantum quenches in 3D quantum magnet $LiHoF_4$

Vasilisa K. Malenkiy
*Mentors: Thomas F. Rosenbaum and Daniel Silevitch*

We demonstrate controlled movement of the ferromagnetic-paramagnetic (FM-PM) phase boundary in the model Ising magnet $LiHoF_4$ and probe quenched domain dynamics using a time-resolved ringdown technique. Hyperfine electronic-nuclear ($^{165}Ho$ spin) coupling increases the critical field. Resonantly pumping the $E_{32}$ $Ho^{3+}$ electronuclear transition (~3 GHz) redistributes state populations, providing intrinsically fast control. Rather than ramping a transverse magnetic field over many minutes, we move the phase boundary, driving the system out of equilibrium in microseconds. We use a fast microwave circuit and loop-gap resonator loaded with a pure $LiHoF_4$ crystal at 30 mK, and measure the evanescent response after switching a detuned probe field off. Down-mixing the resonator's free decay measures the resonant frequency $f_0$ and quality factor Q, yielding the susceptibility of the sample, $\Delta f_0/f_0 \approx -\eta\chi'$ and $\Delta Q^{-1} \approx \eta\chi''$. Mapping $f_0$ across pump power and transverse field traces the phase boundary $P_c(B_z)$. Gating the drive at controlled rates quenches the system across the PM→FM boundary, and the resulting $\chi'(t)$ and $\chi''(t)$ time series - tracking collective-mode softening and domain wall dissipation - will resolve how topological domain-wall density scales with quench rate, constituting the first experimental test of Kibble-Zurek scaling in a macroscopic three-dimensional quantum magnet.

**Simulating and tracking domain evolution in the quantum Ising ferromagnet $LiHo_{0.65}Y_{0.35}F_4$**
Umar H. Mohammad
*Mentors: Thomas F. Rosenbaum and Daniel Silevitch*

Magnetization reversal in a ferromagnet occurs through discrete jumps in an ensemble of domains, which, when detected with an inductive pickup coil, produce audible signals known as Barkhausen noise. At low temperatures, ferromagnets in the $LiHo_xY_{1-x}F_4$ family can exhibit quantum-tunneling-driven domain dynamics, producing "quantum Barkhausen noise". However, experiments can only measure bulk properties, limiting the resolution at which they can describe the behavior of individual domains. To study these microscopic effects, I simulate the hysteresis of $LiHo_{0.65}Y_{0.35}F_4$ using a Metropolis Monte Carlo method with acceptance criteria adding a transverse-field-dependent tunneling term in parallel to the standard thermal term. I developed algorithms to identify domains and track their evolution by maximizing intersection-over-union between frames, formulated as a linear assignment problem. I found that the domain count is bimodal during magnetization reversal, that domain sizes are approximately power-law distributed, and that domain nucleation occurs earlier with a stronger transverse field.

**Phase space dynamics and systematic error analysis at the τSPECT experiment**
Alexander E. Oliver
*Mentors: Brad W. Filippone and Xiaozhe Zhu*

Measurement of the free neutron lifetime to a high level of precision is important for multiple applications in fundamental physics, including extracting the up-down element of the Cabibbo-Kobayashi-Maskawa matrix without nuclear corrections, and the estimation of relative abundances of elements after Big Bang Nucleosynthesis. As measurements have become more precise, lifetime values taken from 'beam' and 'bottle' experiments have diverged to a statistically significant level. It is theorised that this may be due to physics beyond the Standard Model, but systematic errors in both experiments must be fully understood before any conclusions can be made. τSPECT is a 'bottle' experiment that aims to reduce systematic errors caused by neutrons colliding with walls by utilising full magnetic confinement. It is possible for neutrons with energies higher than the depth of the trap to remain confined for finite lengths of time. These 'marginally trapped' neutrons lead to underestimates of the lifetime due to the possibility of them being lost through non-decay means before the detection phase of the experiment. Hence, 'cleaning' is performed before storage to remove these neutrons. We investigate the effect of marginally trapped neutrons on the lifetime measurement, showing that with current cleaning methods the lifetime measurement will be skewed by an amount greater than the goal uncertainty of half a second. Diffuse and reflective collisional elements are simulated to demonstrate the efficacy of mixing and collimation on the cleaning phase. The effect of moving geometry on the phase space is also explored, with neutron cooling on the order of 1 neV observed.

**Removing AGN contamination from millimeter-wave datasets to refine multiprobe triaxial analysis of galaxy clusters**
Chandrasekhar Kappagantula
*Mentors: Jack Sayers, Adriana Gavidia, and Harshda Saxena*

The standard hierarchical model indicates that the formation of galaxy clusters, the largest gravitationally-bound structures known so far, are modelled better by a triaxial shape, rather than a simpler, spherically-symmetric model. Thus, parameters of a galaxy cluster can be biased if modelled spherically, and a triaxial fit requires deep, multiprobe analysis with various datasets. The Cluster Heritage project with XMM-Newton - Mass Assembly and Thermodynamics at Endpoint of structure formation (CHEX-MATE) sample contains 122 galaxy clusters which have been triaxially modelled, but one of the observables used to constrain the line of sight (LOS) and geometry, the Sunyaev-Zeldovich (SZ) effect, is at risk of contamination from Active Galactic Nuclei present in the foreground or at the center of these clusters, as a Brightest Cluster Galaxy (BCG). The SZ effect, a result of inverse-Compton scattering of CMB photons gaining energy from high-energy electrons in the cluster, is used to map and constrain intracluster pressure; thus, AGN contamination can bias pressure profiles and thus the triaxial geometry determined from the fitting. This project contains two key steps to mitigating this contamination: 1) Locate AGN contamination using the NRAO VLA Sky Survey (NVSS) and Very Large Array Sky Survey (VLASS) radio catalogs, extrapolating the fluxes of any located targets at 1.4 GHz and 3 GHz respectively to 90 GHz, roughly estimating the flux of the contaminant in the SZ effect map, and 2) Creating masks for the contamination on the SZ effect maps and fitting the newly masked observables, to evaluate if the bias is reduced. Despite the practical difficulties of locating the AGN contamination and evaluating which masks are best suited to optimally reduce fitting bias, the general procedure has proven to be effective for certain clusters, such as PSZ2 G073.97-27.82 (Abell 2390).

**Covariance computation of CMB lensing power spectrum**
Chi Suen Leung
*Mentors: Wai Ling Wu and Nicolas C. Ferree*

The cosmic microwave background (CMB) provides a powerful probe of both the physics of the early Universe and the growth of large-scale structure. In particular, weak lensing by intervening matter remaps the primordial CMB temperature and polarization anisotropies, inducing statistical mode coupling that can be used to reconstruct the lensing field. The resulting CMB lensing power spectra thus could serve as a robust probe for inference of cosmological parameters through a Gaussian likelihood which require an accurate modelling of the covariance matrix.

This project aims to compute the analytical bandpower covariance between lensing power spectra reconstructed with quadratic estimators from Planck, SPT-3G, and ACT-DR6, and to validate the calculation with Monte Carlo simulations. Neglecting cross-experiment covariance would produce unrealistically tight cosmological constraints, while overestimating it would weaken them. The autocovariances include both lensing cosmic variance and reconstruction noise, with additional mode coupling induced by survey masks. We focus on zero-mean Gaussian reconstruction noise uncorrelated with the lensing signal. Cross-covariance arises from overlapping sky coverage, where experiments observe the same lensing realization, and from correlated reconstruction noise. Preliminary results for the SPT-3G winter field show signal and noise cross-correlations of 23.4% and 12.5% with ACT, and 22.8% and 1.2% with Planck, respectively. We will extend this analysis to the SPT-3G summer and wide fields, where larger sky overlap is expected to increase these correlations.

**Initial data dependence of direct waves in binary black hole mergers**
Patrick P. Chen
*Mentors: Yanbei Chen and Andrew Laeuger*

Black hole mergers consist of an inspiral, merger, and ringdown phase. The ringdown consists primarily of quasinormal modes(QNMs), decaying sinusoids resulting from free oscillation of the remnant black hole. The merger consists of the direct wave, the last part of the wave sourced by the plunging particle, and can carry signatures of the black hole horizon. QNMs have larger amplitudes than the direct wave, so we apply a frequency domain rational filter, which cancels out the QNM poles, and a full filter based on the response term in the drive-response decomposition of a perturbation waveform, to numerical relativity simulations from the Simulating eXtreme Spacetimes(SXS) catalog in order to extract the direct wave. We find a remnant wave whose complex frequency evolves with increasing decay rate and whose properties are primarily dependent on the spin of the remnant black hole. The direct wave can potentially be used as an additional method for inferring remnant black hole properties used alongside standard QNM analysis.