Session P Abstracts

On-shell constraints and the emergence of supersymmetry
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The traditional formalism of Quantum Field Theory is one plagued by redundancies, non-uniqueness, and heavy algebra, wherein fields and Lagrangians dominate the stage, while also being opaque to the little group representation theory, which classifies particles. By recasting the subject in on-shell terms, spacetime symmetries and unitarity take on the key role of constraining possible theories. In the convenient language of spinor-helicity, three-point amplitudes are fixed completely by little group weights, and when considering amplitudes of massless spin 1 particles, one instantly arrives at the need for a Yang-Mills structure and charge conservation. The analogous analysis on massless spin 2 particles yields the universality and diagonality of gravity. Unitarity, via consistent factorization requirements, constrains charged particles to spin less than 3/2 and does not allow gravity to couple to particles of spin greater than 2. Extending this analysis to massless Schwinger-Rarita fields, supersymmetry emerges through the need for factorization, and the super-Yang-Mills and supergravity supermultiplets are uniquely determined. Finally, analyticity and positivity requirements on partial-wave expansions impose bounds on high-energy amplitude behavior, strongly constraining the space of UV-completable low-energy amplitudes.

Mapping emission features of the interstellar medium with SPHEREx
Giulia Murgia
Mentors: James J. Bock and Ari J. Cukierman

The Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx) is a NASA mission designed to perform a full-sky near-infrared spectral survey between 0.75 and 5 μm. This work analyzes SPHEREx observations to create line maps of spectral features in the Galactic plane, with particular focus on the 3.3 μm emission feature of polycyclic aromatic hydrocarbons (PAHs). We implemented continuum filtering to isolate line emission and applied source masking, sigma clipping, and auroral contamination removal using template fitting techniques to improve map quality. To reduce the influence of zodiacal light, analyses were restricted to a ±10° band around the Galactic plane, where interstellar dust emission dominates. These methods enabled the construction of extended line maps of PAHs and hydrogen recombination features, providing new large-scale views of diffuse structures in the interstellar medium and enabling cross-correlation studies with other surveys of thermal dust emission.

Improving boresight pointing of the BICEP/Keck telescopes with CMB data
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Mentors: James J. Bock and Kenny Lau

The BICEP/Keck (BK) experiment aims to measure B-mode polarization in the Cosmic Microwave Background (CMB) to constrain models of cosmic inflation. Built on the Antarctica ice sheet at the South Pole, the BK telescopes use star cameras to calibrate its pointing trajectory, and a CMB-based boresight tracking method was previously developed to reduce reliance on erroneous star camera results through yearly tracking. In this work, we build upon the existing CMB-based method to enable weekly tracking. By independently extracting mount shifts from the correlation of high-precision BK maps with full-sky Planck reference maps at the same frequency in every round of weekly data reduction, the new method enables timely correction of pointing shifts. As modern ground-based

CMB experiments—such as BICEP/Keck, the Simons Observatory (SO), and the South Pole Telescope (SPT)—now feature up to 10^4 detectors, their CMB cameras have surpassed their star cameras in sensitivity. This advancement enables a real-time approach that offers sub-arcminute precision and paves the way for a star camera–independent boresight calibration in the future.

Laser Diode Floating Zone (LDFZ) growth and characterization of ultrahigh-purity crystals for skyrmion qubits
Yingxiao Liao
Mentors: Xuemei Cheng and Stevan Nadj-Perge

A quantum bit, or qubit, is the core entity of quantum computing. Current examples of qubit systems include ultracold atoms, trapped ions, quantum dots, photons, superconducting circuits, and nitrogen-vacancy (NV) centers in diamond. Recently, theorists have proposed magnetic skyrmions, topologically protected swirling spin textures, as a promising candidate for macroscopic qubits due to their topological stability, nanoscale size, and helicity-based characteristics.

Our group plans to apply Laser Diode Floating Zone (LDFZ) technique to grow the bulk single crystals: Gd_2PdSi_3, $GdRu_2Si_2$, $Gd_3Ru_4Al_{12}$, YIG, BiYIG, which are identified by modeling group as hosting nanoskyrmions, to develop potential materials for skyrmion qubits. After crystal growth, X-Ray Diffraction (XRD) method will be used to characterize the crystal's orientation and structure. Additionally, the magnetic and magneto-transport properties of the grown crystals will be investigated using a Physical Property Measurement System (PPMS).

In this summer's research, I will synthesize and characterize the $Gd_3Ru_4Al_{12}$ bulk single crystals. The measured structural and magnetic properties of the grown crystals are expected to contribute to the development of skyrmion-based qubit materials.

Constraining the axion-proton coupling with AGN
Dylan Perez
Mentors: Gian F. Giudice, Elias R. Most, and Sokratis Trifinopoulos

The axion is a theorized spin-0 particle which has been studied extensively for its ability to address several longstanding problems in physics. It was first proposed to explain the observed lack of charge-parity symmetry violation in the strong force, but has since become more widely studied for its viability as a dark matter candidate. The axion's couplings to Standard Model (SM) particles can be derived, allowing for predictions of its effect on observed physical phenomena. In this project, we examine axion production in active galactic nuclei (AGN), which exhibit a range of high-energy phenomena. Particularly, axions can be produced via proton-proton interactions in the accretion disk and by protons accelerated in relativistic jets. By modeling axion production in these regions, we can predict axion detection rates at terrestrial detectors as a function of their coupling to protons, which may allow us to derive novel constraints on the coupling. With more detailed modeling, we may also be able to predict and constrain modifications to the electromagnetic emission from AGN induced by the axion-proton interaction.

Analyzing pulsar anomalies for compact binary searches
Sage H. Stanton
Mentors: Susan V. Gardner and Nick R. Hutzler

Pulsars are neutron stars where we detect pulses of radiation. These are constantly emitted cones focused by the strong magnetic field caused by the neutron stars' rapid rotation, so that we see them as pulses instead of as constant emissions. While not all pulsars emit regular pulses, those that do can be used to probe new physics theories and facilitate searches for new types of dark matter and investigations into the structure of the pulsar itself. This project aims to determine specific effects on a pulsar from being in a binary with a black hole that might make such a binary more easily discoverable. One particular focus is the determination of the modifications of the orbit from the tidal flexing of a neutron star and other sources of energy loss. Working in conjunction with other parts of the project focusing on the spin down variations in ordinary pulsars and the effects from different black hole environments helps create the larger context for the analysis. We hope to later be able to use these results to facilitate the discovery of a pulsar black hole binary utilizing the data from the upcoming Square Kilometer Array and the Caltech Deep Space Radio Array.

Estimating magnetic braking in individual millisecond pulsars to describe local galactic acceleration
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Mentors: Susan V. Gardner and Nick R. Hutzler

Pulsars are rapidly rotating neutron stars that emit electromagnetic radiation through their magnetic poles. The offset between their spin axis and magnetic axis causes these emissions to be received as pulses by outside observers. Millisecond pulsars (MSPs) are a class of pulsars with a spin period of $<$10 ms that typically have incredibly stable spin periods. Still, most pulsars are observed to be gradually slowing down. One source of spindown is the loss of energy due to magnetic radiation. This project aims to estimate energy loss due to magnetic braking by using data from MSPs in binary systems, where other spindown effects are well-characterized. If the spindown due to magnetic braking is understood, then the apparent spindown due to galactic acceleration effects can be better estimated in individual MSPs. From these estimates, we hope to be able to better capture the nuances of the local galactic acceleration field. Moreover, this project is part of a larger effort to search for black hole-pulsar binaries. By characterizing the intrinsic spindown due to magnetic braking, extrinsic spindown effects can be isolated and analyzed with more clarity.

Beyond-Landau phase transitions in D4 non-Abelian topological order
Avinash Vadali
Mentors: Jason F. Alicea and Pablo Sala

Noise is an ever-present factor within all physical systems, yet its effect on the ordering of quantum matter remains poorly understood. In particular, the classification of topological phase transitions induced by Bose condensation remains an open question. This work provides a comprehensive study of the phase diagram of D4 non-Abelian topological order under the proliferation of various species of anyons. We identify quantum phase transitions via classical Monte Carlo simulations and study the resulting phases through effective field theories. Using classical order parameters, we implement a general framework for studying beyond-Landau phase transitions induced by proliferation of anyons with non-trivial mutual statistics. The understanding of phases of D4 developed in this paper can be more generally applied to transitions in numerous 2 + 1D topological orders. Given that D4 is the first non-Abelian topological order to be physically realized, a complete phase diagram for D4 will be instrumental in an accurate assessment of the system’s promise as a topological quantum memory.