2025 Postdoctoral Frontier Symposium in Physics and Astronomy

Wednesday, 24 September 2025 - Friday, 26 September 2025

Tsung-Dao Lee Institute

Book of Abstracts

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Advancing Precision Radial Velocity Towards Detecting Earth Analogs

Author: Lily Zhao[1]

[1] *University of Chicago*

Extreme precision radial velocity (EPRV) measurements, capable of capturing signals with a semi-major amplitude of just 10-30 cm/s, are needed to needed to uncover low-mass planets, inform planet formation scenarios, and reveal atmospheric composition. Achieving this level of precision spectroscopy requires innovation at all levels, from the instrumentation to the extraction software to the astrophysics guiding the final derived RV measurements. I will give an overview of recent advances in the field of EPRV with a focus on data-driven algorithms.

Session Selection:

Astronomy and Astrophysics

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Anisotropy of Nanohertz Gravitational Wave Background and Source Clustering from Supermassive Binary Black Holes Based on Cosmological Simulation

Author: Xiao GuoN[one]

Several pulsar timing array (PTA) groups have recently claimed the detection of nanohertz gravitational wave background (GWB), but the origin of this gravitational wave (GW) signal remains unclear. Nanohertz GWs generated by supermassive binary black holes (SMBBHs) are one of the most important GW sources in the PTA band.

Utilizing data from cosmological simulation, we generate multiple realizations of a mock observable universe that self-consistently incorporates the cosmic large-scale structure, enabling a robust statistical analysis of SMBBH populations and their GW signatures. We systematically investigate the merger event distributions and both the isotropic and anisotropic properties of the resulting GWB signals under different hardening timescales. Specifically, we calculate the characteristic amplitude of the GWB signal, and the angular power spectrum for both the total energy density and energy density in different frequency bins accounting for cosmic variance through different realizations. We also study the clustering pattern of the positional distribution of SMBBHs to examine whether they can reproduce the large-scale structure of galaxies.

Furthermore, for the upcoming Chinese Pulsar Timing Array (CPTA) and Square Kilometre Array (SKA)-PTA, we predict the numbers and signal-to-noise ratio (SNR) distributions of resolvable individual GW sources that may be detected with SNR>8. We finally investigated the impact of weak lensing effects and found that their influence on the basic characteristics of the GWB signal and individual sources is rather limited.

Session Selection:

Astronomy and Astrophysics

Condensed Matter / 6

Pathway to Chiral Conformal Field Theory and its realization via Cavity QED

We explore an integrable deformation of the spin-1/2 Heisenberg spin chain by leveraging its inherent conserved quantities. Starting with the isotropic (XXX) model, we identify the scalar chirality operator as one of its higher conserved charges. This operator, which breaks both time-reversal and parity symmetries, serves as the deformation term. Adding this chiral term to the Hamiltonian produces a new, integrable model whose critical properties are the central focus of this work. We present the model's exact solution via the thermodynamic Bethe ansatz and analyze its critical phenomena. Using entanglement entropy, finite-size scaling, and concepts from symmetry-enriched conformal field theory (CFT), we establish that the chiral deformation drives the system to a c=1 critical point. The low-energy excitations are characterized through the dynamic spin structure factor. Such a scalar chirality operator can be experimentally created via a chiral a cavity. Finally, the presentation concludes with a summary of open problems in the field.

Session Selection:

Condensed Matter

Astronomy and Astrophysics / **7**

AI4Astro: Exploring Star Formation and ISM through Artificial Intelligence

Author: Duo Xu[1]

[1] *CITA, University of Toronto*

The field of astronomy is experiencing a profound shift driven by machine learning, particularly deep learning, which enables efficient processing of vast datasets, surpassing human capabilities in complex data analysis. In this talk, I will showcase the diverse capabilities of AI in astronomy, focusing on tasks related to star formation and the interstellar medium. I will present our AI methodologies, including discriminative and generative models, applied to tasks such as segmenting stellar feedback structures from molecular line data cubes, inferring outflow properties through regression analysis, and determining magnetic field directions. Additionally, we tackle challenging tasks involving the inference of physical quantities like volume density, interstellar radiation field, and magnetic field strength. Through this presentation, I aim to highlight the transformative impact of AI on data analysis in astronomy and encourage exploration of these cutting-edge technologies.

Session Selection:

Astronomy and Astrophysics

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Dark photon dark matter from flattened axion potentials

Authors: Andrew CheekN[one]; Enrico SchiappacasseN[one]; Hong-Yi ZhangN[one]; Leszek RoszkowskiN[one]; Luca VisinelliN[one]; Paola AriasN[one]

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Dark photons can be resonantly produced in the early universe via their coupling to an oscillating axion field. However, this mechanism typically requires large axion-dark photon couplings or some degree of fine-tuning. In this work, we present a new scenario in which efficient dark photon production arises from axion potentials that are shallower than quadratic at large field values. For moderately large initial misalignment angles, the oscillation of the axion field can trigger either efficient dark photon production or strong axion self-resonance via parametric resonance. When self-resonance dominates and disrupts the field's homogeneity, we show that oscillons—localized, oscillating axion field configurations—naturally form and can sustain continued dark photon production, provided the coupling is $\geq O(1)$. For dark photon mass up to three orders of magnitude below the axion mass, the produced dark photons can account for a significant fraction of the present-day dark matter. We support this scenario with numerical lattice simulations of a benchmark model. Our results further motivate experimental searches for ultralight dark photon dark matter.

Session Selection:

Particle and Nuclear Physics

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Geometry, nematicity and transport in strained multi-Weyl semimetals

Authors: Varsha SubramanyanN[one]; Shi-Zeng LinN[one]; Avadh SaxenaN[one]

The minimal coupling of strain to Dirac and Weyl semimetals, and its modeling as a pseudo-gauge field has been extensively studied, resulting in several proposed topological transport signatures. However this insight does not carry over to Weyl semimetals of higher winding number, also known as multi-Weyl semimetals. Using the double-Weyl semimetal as an illustrative example, it is seen that the application of strain splits the higher winding number Weyl nodes to produce an anisotropic Fermi surface, thus acquiring nematic order. The emergent anisotropy modifies the semiclassical equations of motion, as well as the resulting transport signatures resulting in strain-dependent corrections. Specifically, the deformation of the Weyl nodes changes the electric current by an amount proportional to the covariant coupling of the strain tensor and the geometric tensor associated with the Weyl nodes. That is, strain produces geometric signatures rather than topological signatures in multi-Weyl semimetals. Further evidence for this idea is obtained by comparing and contrasting the ways in which simple and double-Weyl semimetals respond to dynamic strain (or sound waves). Finally, I will argue that the most general way to view strain is as a symmetry-breaking field rather than a pseudo-gauge field.

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Condensed Matter

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Tricritical Kibble-Zurek scaling in Rydberg atom ladders

The Kibble–Zurek (KZ) mechanism has been extensively studied in various second-order phase transitions, yet the case of tricriticality—the point where second-order phase transition lines terminate—remains experimentally elusive. Here, we theoretically propose probing KZ scaling at tricritical points using Rydberg atom arrays arranged as two- and three-leg ladders, which realize the tricritical Ising and tricritical Potts universality classes. By slowly ramping the Rabi frequency and detuning, we extract two relevant tricritical exponents, ν and ν', both via conventional paths from the disordered to the ordered phase and via "tangential" paths confined entirely within the disordered phase.

At faster speeds, ramping dynamics go beyond the standard KZ paradigm: data collapse analysis using the parent critical exponents (rather than the tricritical ones) reveals renormalization group flows toward the adjacent second-order critical line, and we identify it as a dynamical analog of Zamolodchikov's c-theorem. Our protocol is readily implementable on existing Rydberg quantum simulators. This provides a direct route to measuring distinct tricritical exponents which can reveal an emergent spacetime supersymmetry constraint $1/\nu - 1/\nu' = 1$. Moreover, this work deepens our theoretical understanding and opens new avenues for exploring beyond-KZ quantum dynamics with rich renormalization group structure.

Session Selection:

Condensed Matter

Astronomy and Astrophysics / 12

3D Magnetic Fields in Galaxy Clusters

Author: Yue Hu[1]

[1] *Institute for Advanced Study*

Magnetic fields are a fundamental component of galaxy clusters, regulating cosmic-ray transport, plasma thermodynamics, and the dynamics of the intracluster medium. Yet their origin, amplification, and three-dimensional structure remain poorly understood, in large part because traditional probes such as synchrotron polarization and Faraday rotation provide only limited, 2D information. A central open question is how cluster mergers and turbulence shape magnetic-field topology and strength, and what role these processes play in cosmic magnetogenesis.

In this talk, I will present new observational evidence linking cluster turbulence and mergers to the amplification of magnetic fields. By exploiting morphological signatures in radio and X-ray data, and guided by advances in turbulence theory, we have developed new diagnostic approaches—including the synchrotron intensity gradient method and machine learning—that allow us to trace the 3D structure of cluster magnetic fields. Applying these tools to high-resolution MeerKAT observations, we have mapped the magnetic fields of several massive clusters, including the extreme merger *El Gordo*, providing direct evidence of turbulence-driven field amplification on mega-kiloparsec scales.

Looking ahead, the synergy of these techniques with upcoming facilities such as LOFAR and the Square Kilometre Array (SKA) will enable systematic surveys of cluster magnetic fields, opening a new observational window on their role in large-scale structure formation and the cosmic origin of magnetism.

Session Selection:

Astronomy and Astrophysics

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A tale of nitrogen enrichment in the Sunburst Arc cluster

Author: Yanlong Shi[1]

[1] *Canadian Institute for Theoretical Astrophysics*

Recent observations of the Sunburst Arc galaxy have uncovered the presence of young ($\sim 2-4\,\mathrm{Myr}$), massive ($M_\star \sim 10^7\,\mathrm{M}_\odot$), and compact ($R_\mathrm{eff} \sim 8\,\mathrm{pc}$) super star clusters. These clusters are characterized by high-pressure, low-metallicity gas ($0.2\,Z_\odot$) with an anomalously elevated nitrogen-to-oxygen ratio $\log(\mathrm{N/O}) \geq -0.5$, deviating from typical empirical relations. In this talk, we present a suite of three-dimensional magnetohydrodynamic simulations of star formation to investigate analogs of the Sunburst Arc supercluster, which initializes from turbulent giant molecular clouds (GMCs) and evolves for 10 Myr. Our results suggest that the progenitor GMC of such a supercluster may have had a mass of $M_\mathrm{cl} \geq 3 \times 10^7\,\mathrm{M}_\odot$ and a radius of $R_\mathrm{cl} \sim 70 \pm 10\,\mathrm{pc}$, yielding a high surface density of $\sim 10^3 - 10^4\,\mathrm{M}_\odot\,\mathrm{pc}^{-2}$. By incorporating chemical feedback from individual very massive stars (VMS), we find that stellar winds from these stars can efficiently enrich the surrounding gas with nitrogen. A significant fraction of this enriched gas is funneled toward the cluster center by gravitational collapse, where it undergoes further enrichment and is irradiated by newly forming VMS, creating the high-pressure gas observed. We conclude that the Sunburst Arc supercluster can be naturally explained by star formation in high-density GMCs that considers VMS-driven feedback, potentially providing indirect evidence for a substantial population of VMS in such environments. We further speculate that the mechanism could also apply to high-redshift, nitrogen enriched galaxies and AGNs recently revealed by the JWST.

Session Selection:

Astronomy and Astrophysics

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Grain Boundaries in Unconventional Superconductors: Vision Transformer–Enabled Coherent Diffraction Imaging

Grain boundaries and domain walls govern connectivity, pinning, and dissipation in unconventional superconductors, yet their internal 3D strain fields are difficult to quantify non-destructively. We combine Bragg Coherent Diffraction Imaging (BCDI) with a physics-informed Vision Transformer using Fourier-aware attention to achieve robust phase retrieval in the multidomain regime. The model enforces a real-space support and minimises a physics-informed loss, yielding sharp domain wall reconstructions and strain maps (via phase gradients) with fewer artefacts than iterative method. Whereas prior BCDI studies typically resolve 5-7 domains, our approach reconstructs up to 19 domains unsupervised. This will enable interface-resolved 3D strain for engineering superconducting and magnetic order.

Session Selection:

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Compact engines of multi-messenger explosions

Author: Luciano Combi[1]

[1] *Perimeter Institute*

The enormous gravitational binding energy rapidly released in compact binary mergers and the collapse of massive stars can power the most luminous transients in the Universe. In the past decade, multi-messenger observations of these violent events have shed light on the nature of plasma at

very high densities and the origin of heavy elements. At the same time, the improvement of computational capabilities has allowed us to construct very detailed numerical models that include many physical ingredients such as General Relativity, weak interactions, and magnetized plasma. In this talk, I will discuss recent progress on theoretical models and open questions regarding compact binary mergers, core-collapse, and their remnants, with a focus on the physics of gas accretion onto neutron stars.

Session Selection:

Astronomy and Astrophysics

Astronomy and Astrophysics / 16

Characterizing Early Cosmic Ecosystems through metal absorption lines with JWST and ALMA

Author: Yunjing Wu[1]

[1] *Steward Observatory/University of Arizona*

The spectra of high-redshift (z ˜ 6) quasars reveal numerous metal absorption lines, yet it remains unclear how early galaxies transported heavy elements from compact star-forming regions into their large-scale (˜100 kpc) gaseous environments. What are the origins of these early metals? How did they reach their observed locations? And what role did they play in cosmic reionization?

In this talk, I will present our recent results of early metal host galaxies using ALMA searches for [C II] 158 μm emission. A pilot observation detects the host galaxy of an [O I] absorber at z = 5.978. Follow-up observations indicate that bright [C II] emitters as absorber hosts are rare, pointing to more complex galaxy properties than predicted by current models. The detected host resides in a dark matter halo of about 4×10^{11} solar masses—more massive than typical simulation predictions—highlighting the potential importance of massive galaxies in early metal enrichment. In addition, possible [C II] emitters at distances greater than 50 kpc suggest that metals can be transported via strong galactic winds. I will also discuss possible environmental effects. JWST/NIRCam wide-field slitless spectroscopy (WFSS) observations systematically examine absorber hosts and their surroundings, with a pilot study identifying a Mg II absorber at z = 5.428 within a galaxy overdensity, suggesting a preference for protocluster environments. Finally, I will outline future directions for circumgalactic medium studies in the JWST era, and share what our results imply for upcoming observations.

Session Selection:

Astronomy and Astrophysics

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Understanding the dissipative behavior of superconducting resonators under variable bath temperature and readout power

Superconducting microwave resonators, developed extensively in the context of Kinetic Inductance Detectors (KIDs), have great potential in astronomical detection due to their multiplexibility, high sensitivity, and ultra-low-noise performance. These detectors rely on sharp resonance curves characterized by high-quality factors (Q factors), which are critical for precise signal readout. However, the resonance properties are highly sensitive to environmental and operational conditions, including bath temperature, readout power, material properties, and geometric design. Understanding and

optimizing these parameters are essential for advancing KID-based astronomical applications. This study focuses on analyzing the resonance behavior of superconducting resonators under a varying bath temperatures and readout powers. The key parameters of interest are the resonance frequency and Q factor, which are influenced by dominant dissipative mechanisms, namely two-level systems (TLS) and quasiparticle heating (QPH). Additionally, the nonlinear effects induced by high readout power are investigated to assess performance degradation in extreme operational regimes. Here, we present systematic measurements of resonance curves and extract resonance parameters across controlled temperature and readout power ranges. The observed data are interpreted using established TLS and QPH loss models to correlate theoretical predictions with empirical results. At low temperatures and powers, TLS losses dominate, while QPH effects become significant at higher power levels and resonance curve distortion is observed beyond a critical readout power threshold. These findings provide critical insights for optimizing superconducting resonator performance in next-generation astronomical instruments, particularly in understanding of KIDs performance limits and balancing sensitivity with dynamic range requirements.

Session Selection:

Condensed Matter

Astronomy and Astrophysics / 20

Investigating the effectively optically thin accretion flow via a unified description of accretion flow

Author: Mingjun Liu[1]

[1] *National Astronomical Observatories, Chinese Academy of Sciences*

Since the 1970s, four basic solutions of the accretion flow have been discovered, namely the Shakura–Sunyaev thin disk, the Shapiro–Lightman–Eardley (SLE) solution, the slim disk, and the advection-dominated accretion flow (ADAF). Although they have achieved great success in interpreting observations in various systems, there are still some questions challenging these theoretical frameworks: i) a self-consistent unified accretion solution has not been established, ii) some observational features, e.g., the soft X-ray excess in active galactic nuclei (AGNs) and the very high state in X-ray binaries (XRBs), cannot be explained by these solutions. In this talk, I will introduce a unified description of various accretion flows and a long-ignored solution–the effectively optically thin accretion flow, which occurs at accretion rates around the Eddington value, bridging the SSD at low accretion rates and the slim disk at high rates. As a consequence of radiation-pressure dominance, the density in an SSD decreases with the increase of accretion rates, making the innermost region effectively optically thin. Further increase in accretion rate leads to a rise in the temperature so that the Compton cooling is able to balance the accretion-released energy. The effectively optically thin flow is characterized by moderate temperature and large scattering optical depth, producing a multi-colour Wien spectrum. Additionally, I will also discuss the spectrum, stability, and potential applications of this new accretion mode.

Session Selection:

Astronomy and Astrophysics

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Imaging excitons of 2D semiconductors in momentum space by tr-ARPES

Excitons - quasiparticles formed by coulomb-bounded electron-hole pairs, play a critical role in the optical response of 2D semiconductors. In monolayer Transition Metal Dichalcogenides (TMDCs) –prototypical 2D semiconductors, the interplay of spin and valley degrees of freedom gives rise to a complex excitonic landscape with significant contributions from the dark excitons which are hidden from the conventional optical spectroscopy. Meanwhile, time- and angle- resolved photoemission spectroscopy (TR-ARPES) has emerged as a powerful technique to study excitons in energy-momentum space [1,2]. In this talk, I will present the recent advances in resolving fine dark excitonic states in 2D semiconductors, elucidating the holistic ultrafast dynamics involving their spin-valley configurations, thereby providing a more comprehensive understanding of fundamental properties. Furthermore, I will discuss their potential for applications and for engineering the exotic nonequilibrium states in semiconductors [3,4].

Reference:
[1] Science Advances 7, eabg0192 (2021).
[2] Nature 603, 7900 (2022).
[3] Nat Commun 16, 6385 (2025).
[4] arXiv:2403.08725.

Session Selection:

Condensed Matter

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Braiding Non-Abelian Anyons on Programmable Superconducting Processors

Author: Zheng-Zhi SunNone

Non-Abelian anyons are exotic quasiparticle excitations hosted by certain topologically-ordered phases of matter. They are the building blocks of topological quantum computing. In this talk, I will first give a brief introduction to non-Abelian anyons and then report two recent experimental quantum digital simulation of braiding non-Abelian anyons on programable superconducting processors. In the first experiment, we prepare the ground states of the toric-code model with twists, and demonstrate that twists behave as Ising anyons, exhibiting the same fusion rules and non-Abelian braiding statistics of the Ising type. They can be explored to encode topological logical qubits and both single- and two-qubit logic gates can be implemented by braiding them. In the second experiment, we exploit efficient quantum circuits to prepare the non-Abelian topologically ordered ground states of the Fibonacci string-net model and demonstrate braidings of Fibonacci anyons featuring universal computational power. In particular, we create two pairs of Fibonacci quasiparticle excitations by acting string operators on the prepared ground states and demonstrate their nontrivial mutual statistics by braiding them with sequences supporting universal single-qubit logic gates.

Session Selection:

Condensed Matter

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Probing Dense Matter and Strong-Field Gravity through Binary Neutron Star Mergers

Author: Yong Gao[1]

[1] *Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Potsdam 14467, Potsdam*

Binary neutron star mergers serve as unique laboratories for studying dense matter and gravity, from finite-size interactions during the late inspiral to the complex dynamics of the post-merger phase. In this talk, I will first discuss the dynamical tides of neutron stars, investigating the roles of compositional stratification, solid components, and possible QCD phase transitions. I examine mode excitations and their imprints in gravitational wave phase shifts, the shattering of crusts, and the associated energy budget available to power electromagnetic precursors. The massive neutron star formed after the merger is heated to several tens of MeV, exhibits strong differential rotation, and undergoes violent oscillations. Studying the system's hydrodynamics and gravitational radiation in detail is essential for placing robust constraints on the hot equation of state. We analyze the post-merger properties with respect to the unknown thermal heating efficiency and the possible development of hydrodynamical instabilities, such as convective and one-armed modes, which provide insight into the thermal and rotational structure. Decoding the equation of state is complicated by uncertainties in the underlying theory of gravity; therefore, it is important to explore the gravity dependence of the entire process. Using massive scalar–tensor gravity as an example, I compare scalar-field effects with tidal signatures in the inspiral and assess their impact on the post-merger waveform. I then highlight the necessity of keeping the matter–gravity degeneracy in mind when probing fundamental physics.

Session Selection:

Astronomy and Astrophysics

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Detecting entanglement with transport measurement in weakly interacting and fluctuating systems

Measuring entanglement entropy in interacting, multipartite systems remains a significant experimental challenge. We address this challenge by developing a protocol to measure von Neumann entropy (VNE) and mutual information in quantum transport systems with both many-body interactions and multiple subsystems. Our analysis indicates that the vital connection between VNE and two-point correlation functions persists under these realistic conditions. The measurement is shown to be feasible for systems with boundary interactions and, critically, for bulk-interacting systems subject to a quantum quench of their internal couplings. Our work provides a pathway to experimentally quantify entanglement in complex interacting systems and establishes mutual information as an experimentally accessible indicator for system-environment entanglement.

Session Selection:

Condensed Matter

Particle and Nuclear Physics / 28

Strange Metals from Disorder

Author: Yili Wang[1]

Co-authors: Sang-Jin Sin [2]; Xian-Hui Ge [3]; Young-Kwon Han [2]

[1] *Hanyang University (KR)*

[2] *Hanyang University*

[3] *Shanghai University*

Strange metals, found in high-temperature superconductors and other strongly correlated systems, display unconventional transport such as robust linear-in-temperature resistivity that defies Fermi liquid theory. My research explores a disorder-driven approach inspired by the Sachdev–Ye–Kitaev (SYK) model, showing that linear resistivity persists under scalar and vector random couplings, even in magnetic fields. Beyond transport, these models suggest a deeper link between disorder and quantum entanglement: our recent work connects disorder averages to wormhole and entanglement structures, providing a concrete realisation of the ER=EPR conjecture. These results point towards a unified framework of strange metals that bridges disorder, entanglement, and holography.

Session Selection:

Condensed Matter

Astronomy and Astrophysics / 29

The Formation of Direct Collapse Black Holes at Cosmic Dawn and 21 cm Global Spectrum

Author: Meng Zhang[1]

Co-authors: Bin Yue [1]; Yidong Xu [1]; Andrea Ferrara [2]

[1] *National Astronomical Observatories, Chinese Academy of Sciences*

[2] *Scuola Normale Superiore*

The existence of supermassive black holes (SMBHs) at $z > 6$ poses a profound challenge to our understanding of their formation and growth. This long-standing puzzle is intensified by recent JWST discoveries of accreting SMBHs at $z \sim 7-10$ with inferred masses up to $\sim 10^{7-8}\mathrm{M}_\odot$, which require the formation of massive seeds followed by rapid, sustained accretion. A leading explanation is the direct collapse black hole (DCBH) channel, in which $\sim 10^4 - 10^6\,\mathrm{M}_\odot$ seeds form from the monolithic collapse of pristine, metal-free gas in atomic-cooling halos ($T_{\rm vir} \geq 10^4\,\mathrm{K}$). This process requires intense UV radiation from nearby primordial galaxies to suppress H_2 formation, rendering DCBHs intrinsically rare. However, the overabundance of high-z galaxies revealed by JWST could facilitate DCBH formation—potentially explaining the unexpectedly abundant faint AGNs (the so-called "Little Red Dots") at $z \sim 4-5$. On the other hand, X-ray radiation from these same galaxies can catalyze H_2 formation, potentially suppressing DCBH formation.

In this talk, I will present our work that quantifies the radiative impact of the first galaxies on the abundance of DCBH. Using UV luminosity function models calibrated to the latest JWST observations, we investigate the complex interplay between UV and X-ray radiation that governs DCBH formation in a realistic cosmic environment. Our results show that while more efficient star formation promotes DCBH creation, the accompanying X-rays act as a strong regulator of their final abundance. The most exciting insight from our study is a novel link between the abundance of DCBHs and the 21 cm global signal from Cosmic Dawn. The depth of the 21 cm absorption feature is highly sensitive to the X-ray background, which is dictated by the same intrinsic galactic X-ray properties that modulate DCBH formation. I will present this fundamental connection and highlight the potential of the 21 cm signal to serve as a novel probe of DCBH formation rate, opening a fresh window into the birth of the first giants in the early Universe.

Session Selection:

Astronomy and Astrophysics

Astronomy and Astrophysics / 30

Data-Driven Approaches for Gravitational-Wave Waveform Modeling

Author: Ruijun Shi[1]

[1] *Beijing Normal University*

Accurate modeling of gravitational-wave (GW) waveforms is a crucial component of GW detection and parameter estimation. The waveform templates for GW astronomy are primarily based on the effective-one-body framework and the phenomenological framework. However, in the case of binary systems with complex orbital dynamics, such as eccentric binaries, these waveform templates still face challenges in terms of computational efficiency or accuracy. Over the past decade, reduced-order modeling has significantly accelerated the generation of accurate waveforms, leading to the development of a series of numerical relativity surrogate models. Meanwhile, the rapid progress of machine learning has given rise to a new generation of data-driven surrogate models. In this talk, I will briefly review the current state of data-driven waveform modeling and present our recent work on a deep learning-based model for rapid generation of eccentric binary black hole (BBH) waveforms. Furthermore, I will discuss the potential applications of such data-driven approaches in gravitational-wave astronomy.

Session Selection:

Astronomy and Astrophysics

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Cavity-modified quantum Hall phases

Quantum vacuum fluctuations are usually negligible in solid-state systems due to their minimal strength. They have traditionally been linked to phenomena such as spontaneous emission and the Casimir effect. Recent advances in cavity engineering, however, allow for extreme compression of the photonic mode volume, enhancing considerably the vacuum electric field strength and driving light–matter interactions into the ultra-strong coupling regime.

Quantum Hall systems have provided a fertile platform for discovering new physics for more than four decades, and their coupling to the vacuum has recently attracted both experimental and theoretical attention.

In this talk, I will review recent experimental progress in the field and present our theoretical contributions. We show how electronic correlations are affected by the emergence of a cavity-mediated effective interaction that is attractive and long-ranged. This interaction modifies spin splittings driven by exchange interactions and, perhaps more remarkably, stabilizes certain fractional quantum Hall (FQH) phases. Using exact diagonalization, semi-analytical approaches, and Monte Carlo simulations, we show that these interactions indeed increase the excitation gap, a key measure of the FQH state' s robustness.

References:

J. Enkner, L. Graziotto, D. Boriçi, F. Appugliese, C. Reichl, G. Scalari, N. Regnault, W. Wegscheider, C. Ciuti, and J. Faist, "Tunable vacuum-field control of fractional and integer quantum hall phases," Nature 641, 884–889 (2025)

D. Boriçi, N. Regnault, and C. Ciuti, "Cavity-modified fractional quantum hall phases," in preparation (2025)

D. Boriçi, G. Arwas, and C. Ciuti, "Cavity-modified quantum electron transport in multiterminal devices and interferometers," Phys. Rev. B 112, 045301 (2025)

C. Ciuti, "Cavity-mediated electron hopping in disordered quantum Hall systems," Physical Review B 104 (2021).

F.Appugliese, J.Enkner, G.L.Paravicini-Bagliani, M.Beck, C.Reichl, W.Wegscheider, G.Scalari, C.Ciuti, and J.Faist, "Breakdown of topological protection by cavity vacuum fields in the integer quantum Hall effect," Science 375, 1030–1034 (2022)

Session Selection:

Condensed Matter

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Symmetry-protected many-body states in superconducting quantum circuits

We propose an interacting many-body spin model with nearest-neighbor and next-nearest neighbor couplings, where the two lowest eigenstates form a qubit manifold that is protected by symmetry from both relaxation and dephasing caused by local perturbations. We map the spin model to a superconducting circuit and show that such a circuit can reach coherence times exceeding several milliseconds in the presence of realistic environmental noise. The control of the device can be realized by the STIRAP scheme using higher energy states of the device, which also contribute to the dispersive readout of the device. Such a design may deliver improved performance relative to existing superconducting qubits.

Session Selection:

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Particle and Nuclear Physics / 35

Unitarity of Higgs inflation and R^2 correction

Authors: Minxi He[1]; Kyohei Mukaida[2]; Kohei Kamada[3]

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[3] *Hangzhou Institute for Advanced Study*

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The Standard Model Higgs field can play an essential role in the very early Universe to realize the cosmic inflation, providing proper initial conditions for the hot big bang theory. However, the vanilla Higgs inflation model suffers from the unitarity problem when the Higgs field decays into gauge bosons after inflation, as the momentum of the produced gauge bosons can be higher than the UV cutoff of the model. Such inconsistency can be resolved by considering the UV extended Higgs inflation with an R^2 operator. In this talk, I will introduce a new geometric method to unambiguously determine the cutoff scale of general nonlinear sigma models, including the Higgs inflation, and discuss the unitarity problem of the Higgs inflation. I will show that the R^2 corrected model, namely the mixed Higgs-R^2 inflation, is free from such problem up to Planck scale and has rich phenomenology during reheating.

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Particle and Nuclear Physics

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Gamma-Ray and AntiMatter survey(GRAMS) experiment

Author: JIANCHENG ZENG[1]

[1] *Northeastern University*

The Gamma-Ray and AntiMatter Survey (GRAMS) is a next-generation experiment using a Liquid Argon Time Projection Chamber (LArTPC) detector to detect gamma rays and antiparticles. Gamma-ray surveys are important for understanding multi-messenger and time-domain astronomy, enabling exploration of the universe's most potent events, such as supernovae and neutron star mergers etc. Despite the significance of MeV gamma-rays, GRAMS could also explore the so-called 'MeV gap' region to improve MeV gamma-ray measurement sensitivity that was restricted by the hardness of accurately reconstructing Compton events. Aside from gamma-ray detection, the GRAMS proposed method also serves as an antiparticle spectrometer, targeting low-energy range cosmic-ray measurement. This talk will provide updates on the current status and progress towards the first prototype balloon flight with a small-scale LArTPC (pGRAMS) scheduled for early 2026, as well as the recent progress on antihelium-3 sensitivity calculation.

Session Selection:

Astronomy and Astrophysics

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The competition between two irreducible representations that leads to re-emergent BTRS superconducting state under uniaxial stress and type 1.5 superconductivity

We consider a general microscopic model describing a square (rectangular after distortion) lattice with nearest-neighbor interaction potential. We study the stress-induced splitting between $U(1)$ and $\mathbb{Z}_2$ superconducting critical temperatures. We find that broken time-reversal symmetry (BTRS) $s + id$ state generally has decreasing critical temperature under strain. However, in some range of Poisson ratio (the ratio of transverse strain to longitudinal strain), the behavior is nonmonotonic: First, drop (can be down to 0) and further increase of $\mathbb{Z}_2$ critical temperature under compressional strain increase.
In the second part of the talk, we focus on unstrained square lattice and evaluate superconducting phase diagram. Within certain parameter space of phase diagram we find type 1.5 superconducting behavior with vortex clusters. This behavior occurs when ground state has two non-zero superconducting order parameters and magnetic penetration depth satisfies $\xi_1 < \lambda < \xi_2$, where ξ is coherence length, hence realizing a superconducting state falling outside of type-I/type-II dichotomy. We discuss the conditions where this behavior is realized in pure d-wave or pure s-wave systems.

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Particle and Nuclear Physics / 39

Cosmological First-order Phase Transition Aspects: Supercooling and Gauge Invariance

Author: Jinzheng Li[1]

[1] *Northeastern University (Boston)*

We examine first-order phase transitions within a hidden $U(1)_X$ sector as potential sources of stochastic gravitational wave backgrounds, with particular emphasis on supercooling and gauge invariance considerations. We establish that supercooled phase transitions provide a viable mechanism for explaining observed pulsar timing array signals and demonstrate that the distinct thermal evolutionary pathways of hidden and visible sectors exert substantial influence on the resulting gravitational wave power spectrum. Additionally, we identify that gauge-dependent formulations can introduce significant systematic uncertainties in gravitational wave predictions for supercooled phase transitions. To address this limitation, we develop a manifestly gauge-invariant computational framework based on the Metaxas–Weinberg formalism, specifically adapted for the analysis of supercooled phase transition dynamics.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 40

Implications of Topological Field Configurations for Baryon Asymmetry and Dark Matter

Author: Yanda WuNone

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Topological field solutions –such as sphaleron, monopole, and cosmic strings –can have important implications on the unsolved questions of our universe, notably the origin of baryon asymmetry and the nature of dark matter. Many baryogenesis mechanisms (for example, electroweak baryogenesis and leptogenesis) depend on sphaleron transition; consequently, a theoretical rubost and consistent computation of sphaleron rate is essential. Monopoles or cosmic strings (e.g., in Abelian–Higgs models) that arise in many beyond the Standard Model (BSM) scenarios can alter the relic abundance of WIMPs and/or axion-like particles (ALPs). I discuss recent progress in computing sphaleron rate and examine the impact of topological defects on dark-matter relic densities.

Session Selection:

Particle and Nuclear Physics

Astronomy and Astrophysics / 41

Populations of evolved massive binary stars in the Small Magellanic Cloud I: Predictions from detailed evolution models

Author: Xiao-Tian Xu[1]

Co-authors: Abel Schootemeijer [2]; Andrea Ercolino [2]; Ben Hastings [2]; Chen Wang [3]; Christoph Schürmann [2]; Danny Lennon [4]; Frank Haberl [5]; Koushik Sen [6]; Michael Kramer [7]; Norbert Langer [2]; Pablo Marchant [8]; Selma de Mink [9]; Thomas Tauris [10]; Tomer Shenar [11]

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[3] *Nanjing University*

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[5] *Max-Planck-Institut für Extraterrestrische Physik*

[6] *University of Arizona*

[7] *Max-Planck-Institut für Radioastronomie*

[8] *Ghent university*

[9] *Max-Planck-Institut für Astrophysik*

[10] *Aalborg University*

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Context. The majority of massive stars are born with a close binary companion. How this affects their evolution and fate is still largely uncertain, especially at low metallicity.

Aims. We derive synthetic populations of massive post-interaction binary products and compare them with corresponding observed populations in the Small Magellanic Cloud (SMC).

Methods. We analyse 53298 detailed binary evolutionary models computed with MESA. Our models include the physics of rotation, mass and angular momentum transfer, magnetic internal angular momentum transport, and tidal spin-orbit coupling. They cover initial primary masses of 5—100$M_{\odot}$, initial mass ratios of 0.3—0.95, and all initial periods for which interaction is expected, 1—3162 d. They are evolved through the first mass transfer and the donor star death, a possible ensuing Be/X-ray binary phase, and they end when the mass gainer leaves the main sequence.

Results. In our fiducial synthetic population, 8% of the OB stars in the SMC are post-mass transfer systems, and 7% are merger products. In many of our models, the mass gainers are spun up and expected to form Oe/Be stars. While our model underpredicts the number of Be/X-ray binaries in the SMC, it reproduces the main features of their orbital period distribution and the observed number of SMC binary WR stars. We further expect ~50 OB+BH binaries below and ~170 above 20 d orbital period. The latter might produce merging double BHs. However, their progenitors, the predicted long-period WR+OB binaries, are not observed.

Conclusions. While the comparison with the observed SMC stars supports many physics assumptions in our high-mass binary models, a better match of the large number of observed OBe stars and Be/X-ray binaries likely requires a lower merger rate and/or a higher mass transfer efficiency during the first mass transfer. The fate of the initially wide O star binaries remains particularly uncertain.

Session Selection:

Astronomy and Astrophysics

Condensed Matter / 42

High Symmetric Sites Induced Unprecedented Ultra-Large-Period Moiré Lattice in Twisted Trilayer MoS2

Twisted trilayer (Tt) transition metal dichalcogenides with their multiple rotational degrees of freedom offer unprecedented opportunities for the formation of large-wavelength moiré superlattices to maximize the effect of correlated behaviors. However, precisely stacking trilayer structures to realize ultra-large-wavelength moiré superlattices with a deep moiré potential remains a significant challenge, hindering investigations of moiré-tuned many-body excitonic properties. Here we directly fabricate Tt MoS2 homostructures via chemical vapor deposition, in which two commensurate twists of 2.7° and 21.9° are sequentially introduced from the top to middle, and to bottom layers. An unprecedented super-moiré structure with an ultra-large periodicity of around 24 nm is achieved in the 2.7°/21.9° Tt MoS2, which is hierarchally composed by periodical mirror-symmetric triangular tessellation patterns consisting of five different kinds of high-symmetric stacking registrations and the relaxation regions resulting from the interlayer gliding. This robust ultra-large-period super-moiré structure generates a deep moiré potential to effectively limit the intralayer moiré excitons recombination associated with the enhanced layer-locked valley polarization by 2-fold larger than that of the trilayer systems with incommensurate angles. Our work presents angle-dependent super-moiré architectures in Tt systems as a versatile platform for designing moiré quantum materials with tailored optoelectronic responses, advancing applications in valleytronic and excitonic devices.

Session Selection:

Condensed Matter

Particle and Nuclear Physics / 43

Reconstructing Laurent expansion of rational functions using p-adic numbers

Authors: Tianya XiaNone; Li Lin YangNone

We propose a novel method for reconstructing Laurent expansion of rational functions using p-adic numbers. By evaluating the rational functions in p-adic fields rather than finite fields, it is possible to probe the expansion coefficients simultaneously, enabling their reconstruction from a single set of evaluations. Compared with the reconstruction of the full expression, constructing the Laurent expansion to the first few orders significantly reduces the required computational resources. Our method can handle expansions with respect to more than one variables simultaneously. Among possible applications, we anticipate that our method can be used to simplify the integration-by-parts reduction of Feynman integrals in cutting-edge calculations.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 44

Global analysis of fragmentation functions to light neutral hadrons

Author: 重阳刘 [1]

[1] 上海交通大学粒子物理与核物理研究所

Fragmentation functions (FFs) are crucial non-perturbative components in quantum chromodynamics (QCD), playing a vital role in predictions and understanding of the hadronization process. In

this paper, we present the FFs for K_S^0, \eta, \pi^0 mesons, and \Lambda baryons in the context of global QCD analysis. The data included in the fit are from single inclusive e^+ e^- annihilation (SIA), semi-inclusive deep-inelastic scattering (SIDIS) and proton-proton collisions, with kinematic cuts carefully applied to ensure validity of collinear factorization and perturbative QCD expansion. For the first time, data from SIDIS and hadron-in-jet production in SIA have been incorporated into the extraction of FFs for light-flavor neutral hadrons. Our analysis reveals that these data play a critical role in constraining the gluon distribution, and in distinguishing between different quark flavors. Pulls from different datasets are also studied by performing alternative fits with systematically subtracting groups of data from the nominal fit. For the quality of the fit, good \chi^2 values are achieved for most of the datasets, and FFs are generally well constrained within the momentum fraction region \pqty{0.1, 0.5}. The extracted K_S^0 fragmentation functions, together with the K_S^0 FFs constructed from K^{\pm} FFs via isospin symmetry, are used to test isospin symmetry in kaon fragmentation. Although a definitive conclusion cannot be reached yet, these studies have identified several potential measurements that can be performed at existing facilities, which may ultimately help us to arrive at a conclusive answer. With the comprehensive species of FFs extracted within the NPC framework, we are able to perform a test on the momentum sum rule with the light-flavor charged and neutral hadrons.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 45

Foundation Models for Collider Physics: AI as a Tool for Discovery

Author: Yulei ZhangN[one]

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Experiments at the Large Hadron Collider produce some of the most complex datasets in science. A central challenge in high-energy physics is to extract rare signals, reconstruct invisible particles such as neutrinos, and search for subtle deviations from the Standard Model with maximal sensitivity. These are fundamentally physics problems, but their scale and complexity call for new strategies.

In this talk, I will present EveNet, a large-scale foundation model developed for collider physics. Trained on billions of simulated events, it provides a common starting point for diverse analysis tasks, including improving search sensitivity, reconstructing hidden structures, and detecting unexpected anomalies. By integrating such methods into the physicist’s toolkit, we show how foundation models can accelerate discovery and open new directions in the exploration of fundamental laws of nature.

Session Selection:

Particle and Nuclear Physics

Condensed Matter / 46

Interfacial magnetic spin Hall effect in van der Waals heterostructure

The spin Hall effect (SHE) allows efficient generation of spin polarization or spin current through charge current and plays a crucial role in the development of spintronics. While SHE typically occurs in non-magnetic materials and is time-reversal even, exploring time-reversal-odd (T-odd) SHE, which couples SHE to magnetization in ferromagnetic materials, offers a new charge-spin conversion mechanism with new functionalities. Here, we report the observation of giant T-odd SHE in van der Waals ferromagnetic heterostructure, representing a previously unidentified interfacial magnetic spin Hall effect (interfacial-MSHE). Through rigorous symmetry analysis and theoretical calculations, we attribute the interfacial-MSHE to a symmetry-breaking induced spin current dipole at the vdW interface. Furthermore, we show that this linear effect can be used for implementing multiply-accumulate operations and binary convolutional neural networks with cascaded multi-terminal devices. Our findings uncover an interfacial T-odd charge-spin conversion mechanism with promising potential for energy-efficient in-memory computing.

Session Selection:

Condensed Matter

Astronomy and Astrophysics / 47

Asteroseismology-driven Studies of Stellar Core Magnetic Fields, Rotation Rates, and Age Determinations

Author: Gang Li[1]

[1] *KU Leuven*

Stars are the fundamental building blocks of the Universe. Their dynamics, nucleosynthesis, and supernova explosions are closely linked to the formation and evolution of the Milky Way, the chemical enrichment of galaxies, and even cosmology. Although modern stellar theory has achieved great success, the physical processes in stellar cores remain highly uncertain because the interior cannot be directly observed by traditional methods, limiting the understanding of stellar evolution theory. Asteroseismology, the only technique capable of efficiently probing stellar interiors, is playing an increasingly important role in the era of space-based observations. The oscillation modes inside stars are modulated by their internal physical conditions, leading to measurable changes in frequency and amplitude; once these waves reach the surface, they appear as periodic brightness variations. By precisely measuring the oscillation frequencies, we can infer the internal structure and evolutionary state of stars.
In this talk, I will present several recent advances made using Kepler and TESS asteroseismic data. First, among more than 2,000 red giants, we detected magnetism-induced signals in over a dozen stars, yielding magnetic field strengths of 20–150 kG—the most direct evidence of strong internal fields in stars to date. Second, through large-sample analyses of gravity and mixed modes, we constrained the core and envelope rotation rates of thousands of main-sequence and red giant stars, revealing significant discrepancies with theoretical predictions and providing crucial constraints on angular momentum transport mechanisms. Finally, I will show how combining asteroseismic analysis of open clusters (e.g., NGC 2516) with isochrone fitting enables highly precise age determinations, offering a new approach to measuring cluster ages.

Session Selection:

Astronomy and Astrophysics

Particle and Nuclear Physics / 48

Higgs hadronic decay at CEPC

Authors: Xinzhu Wang[1]; Chunxiang Zhu[1]; Yifan Zhu[1]; Kun Wang[2]; Haijun Yang[1]

[1] 上海交通大学

[2] 上海理工大学

We conduct a detailed Monte Carlo study of the process $e^+e^- \longrightarrow ZH$ at the CEPC. The analysis focuses on final states where the Z boson decays either invisibly or into charged leptons, while the Higgs boson decays hadronically through $H \longrightarrow b\bar{b}$, $c\bar{c}$, gg and $s\bar{s}$. To distinguish among hadronic final states, we apply advanced jet-tagging methods based on ParticleNet, Particle Transformer, and the More-Interaction Particle Transformer, which make use of low-level particle information for more accurate classification. In addition, we develop a machine-learning-based event selection strategy to strengthen signal–background separation, leading to improved sensitivity in Higgs property measurements and stringent tests of Standard Model predictions at the CEPC.

Session Selection:

Particle and Nuclear Physics

Condensed Matter / 51

Non-Hermitian Fermi-Dirac Distribution and Applications in Quantum Transport

In this talk, I will introduce the theory of persistent current transport in non-Hermitian quantum systems, building on the foundation of Hermitian superconducting-normal-superconducting junctions. I will then extend the system to incorporate dissipation using non-Hermitian quantum Hamiltonians. By employing Green' s function formalism, I will show the emergence of a non-Hermitian Fermi-Dirac distribution that allows us to derive an analytical expression for the persistent current that depends solely on the complex spectrum. This formula is applied to two dissipative models: (i) a phase-biased superconducting-normal-superconducting junction, and (ii) a normal mesoscopic ring threaded by a magnetic flux. I will demonstrate that the persistent currents in both systems exhibit no anomalies at emergent exceptional points, whose signatures instead become apparent in the current susceptibility. These results, validated by exact diagonalization, are further extended to include finite temperature and interaction effects. I will conclude by discussing potential applications of this formalism in identifying Majorana zero modes and its relationship with symbolic AI.

Reference:

P.-X. Shen, Z. Lu, J. L. Lado, and M. Trif, Non-Hermitian Fermi-Dirac Distribution in Persistent Current Transport, Phys. Rev. Lett. 133, 086301 (2024) (Editors' Suggestion).

Session Selection:

Condensed Matter

Particle and Nuclear Physics / 53

Bridging Energy Scales in Neutrino Physics: Insights from JUNO and TRIDENT

Author: Iwan Morton-Blake[1]

[1] *Tsung-Dao Lee Institute / Shanghai Jiao Tong University*

The next generation of neutrino experiments presents unprecedented opportunities to address key questions in particle physics and astrophysics. This talk will summarise recent contributions made in two flagship international experiments: JUNO, a 20,000-ton liquid scintillator detector that has recently entered full data-taking in China, and TRIDENT, a next-generation deep-sea Cherenkov telescope under development in the South China Sea, spanning several cubic kilometres.

On JUNO, I will discuss developments in the reactor neutrino oscillation analysis programme, aiming to make world-leading measurements of critical oscillation parameters, and eventually determine the neutrino mass ordering. Also included are contributions to detector commissioning, and the implementation of a real-time multi-messenger alert system for astrophysical sources.

For TRIDENT, I will present progress on the detector ' s design and physics potential. A detailed neutrino interaction modelling and full-chain simulation framework has been developed to assess the detector ' s capability to discover astrophysical neutrino sources and identify interactions from all neutrino flavours. These studies directly inform detector design optimisation and shapes the physics potential for the full planned array.

Session Selection:

Astronomy and Astrophysics

Particle and Nuclear Physics / 54

Curvature perturbation and GW induced by U(1) symmetry breaking during inflation

Author: Tingyu Li[1]

Co-authors: Chen Yang [1]; Haipeng An [1]

[1] *Tsinghua University*

During inflation, the inflaton can undergo significant changes. If the inflaton field is coupled to other fields, phase transitions may occur in the coupled fields as the inflaton evolves. The curvature perturbations and gravitational waves generated by the phase transition may be detectable and could provide insights about inflation. We explore the possible curvature perturbation and the secondary GW generated by a U(1) symmetry breaking during inflation. We computed the shape characteristics of curvature perturbations and gravitational waves through numerical simulations. In the future, we may be able to understand early universe processes by experimentally observing these physical quantities.

Session Selection:

Astronomy and Astrophysics

Particle and Nuclear Physics / 55

Muon Secondary Particles Study in JUNO Experiment

Author: 浩菁赖 [1]

[1] *Shanghai Jiao Tong University*

The Jiangmen Underground Neutrino Observatory, with the world's largest liquid scintillator detector, has recently completed the detector construction and started data taking. The main purpose of

the experiment is to determine the neutrino mass ordering and perform a precision measurement of the neutrino oscillation parameters. Muon secondary particles play an important role in data analysis. They not only provide natural calibration sources, including spallation neutrons, 11B, and 11C, but also contribute to the background via fast neutrons, 9Li, and 8He. This talk presents an overview of the JUNO experiment and relevant studies on the muon secondary particles in the JUNO detector.

Session Selection:

Particle and Nuclear Physics

Astronomy and Astrophysics / 56

Deep Generative Models for Bayesian Inference in Astrophysics

Author: Biwei Dai[1]

[1] *Institute for Advanced Study*

Deep generative models offer powerful tools for solving astrophysical inference problems by enabling flexible representations of prior knowledge and likelihood functions.

In the first part of the talk, I will discuss how generative models can be employed to construct likelihood functions for cosmological inference at the field level, enabling more effective extraction of information compared to traditional summary statistics like two-point statistics. This simulation-based inference framework facilitates anomaly detection of model misspecification, and enhances interpretability through sample generation. I will present applications to weak gravitational lensing analysis, particularly our ongoing work on applying this approach to the field-level analysis of the Hyper Suprime-Cam (HSC) survey.

In the second part, I will demonstrate how generative models can be used to construct physically informed priors for Bayesian inverse problems. As an application, I will show how this approach enables image reconstruction of AGN accretion disks from intensity interferometry, where only the amplitudes of Fourier modes are measured while phase information is lost. By sampling from the resulting posterior distribution, we achieve high-fidelity reconstructions with uncertainty quantification, outperforming traditional iterative methods across varying noise levels and UV-plane coverage.

Session Selection:

Astronomy and Astrophysics

Particle and Nuclear Physics / 57

Search for Inelastic-scattering signature in PandaX-4T

Author: chencheng hanN[one]

The search for Weakly Interacting Massive Particles (WIMPs) still holds many mysteries. Beyond the well-studied spin-independent (SI) interaction, the spin-dependent (SD) coupling is crucial for determining whether WIMPs can interact with the spin of nucleons.

Typically, SD interactions are searched for in the elastic-scattering region (0-25 keV). However, it is challenging to distinguish between SI and SD models because their energy spectra are very similar.

A key point is that only the SD interaction can excite the nucleus of Xe-129, which can produce a unique inelastic-scattering signature.

In this talk, I will present our research on this inelastic-scattering signal, based on the dataset from the PandaX-4T experiment with a total exposure of 1.54 Tonne-Year.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 58

New Ideas on Indirect Probes of Axions

Author: Huangyu Xiao[1]

[1] *University of Chicago*

The indirect detection of axions can enable us to probe axion parameters with various astrophysical and cosmological observations. In this talk, I will discuss new dynamics and phenomena that are unique to axions, such as the formation of axion miniclusters and axion stars. Then I will introduce some new ideas on testing these new phenomena, which can enhance the sensitivity and motivate more dedicated searches.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 60

Pretraining jet models for physics at the Large Hadron Collider

Author: Congqiao Li[1]

[1] *Peking University*

Deep learning is reshaping how we study jets at the Large Hadron Collider (LHC). By learning from the complex patterns of hadronic activity, modern jet-tagging models are opening new possibilities for discovery. In this talk, I will present our recent advances in building large-scale pretrained models for jets, designed to be broadly applicable across the LHC physics program. Such models can (1) extend the sensitivity of targeted searches and (2) strengthen model-agnostic strategies, thereby unlocking physics opportunities that were previously out of reach. I will highlight the *Sophon* model, a prototype trained on fast-simulation datasets, and then introduce the concept of *Global Particle Transformer* (*GloParT*) models developed within the experiments. I will also provide insights into the underlying deep learning methodologies and discuss future prospects.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 61

Dark Matter Direct detection and Collider Search

Author: Ning Zhou[1]

[1] *Shanghai Jiao Tong University*

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Session Selection:

Particle and Nuclear Physics / 62

Optical imaging of particle tracks in scintillators

Authors: Junting Huang[1]; Xuanye Fu[1]; Yuanhao Zhao[1]; Zhangming Chen[1]

[1] *Shanghai Jiao Tong University*

Corresponding Author: junjie.jiang@sjtu.edu.cn

Optical imaging of alpha tracks in scintillators have been demonstrated in recent years. The imaging of particle tracks has potentials in rare event searches, such as the neutrinoless double-beta decay search. This talk presents the observation and data analyses of alpha particle tracks in a GAGG crystal scintillator using a scientific CMOS camera mounted on an optical microscope. Results on the energy resolution, position resolution, track length and dE/dx are discussed. The alpha track data together with Geant4 simulations show the potential to extend this method to MeV electron tracking in scintillators, which can be useful in identifying double-beta decays.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 63

Bias with a timer: Axion Dark Matter and Domain Wall

Author: Shota Nakagawa[1]

[1] *Tsung-Dao Lee Institute, Shanghai Jiao Tong University*

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QCD axion can explain the strong CP problem and dark matter (DM) simultaneously. If the Peccei-Quinn (PQ) symmetry is spontaneously broken after inflation, string-wall network would dominate the energy density in the Universe. In this talk, we consider a mixing coupling of the PQ scalar with a light scalar field which induces an extra axion potential. When the PQ scalar is mixed nonlinearly, the axion oscillation around the extra potential triggers the formation of stable domain wall. However, the system collapses due to the QCD effect as a bias, resulting in a large amount of dark matter. In addition, by estimating the misalignment production modified by the extra potential, we clarify the total abundance of axion dark matter.

Session Selection:

Particle and Nuclear Physics

Condensed Matter / 64

Measurement-driven quantum advantages in shallow circuits

Quantum advantage schemes probe the boundary between classically simulatable quantum systems and those that computationally go beyond this realm. Here, we introduce a constant-depth measurement-driven approach for efficiently sampling from a broad class of dense instantaneous quantum polynomial-time circuits and associated Hamiltonian phase states, previously requiring polynomial-depth unitary circuits. Leveraging measurement-adaptive fan-out staircases, our "dynamical circuits" circumvent light-cone constraints, enabling global entanglement with flexible auxiliary qubit usage on bounded-degree lattices. Generated Hamiltonian phase states exhibit statistical metrics indistinguishable from those of fully random architectures. Additionally, we demonstrate measurement-driven globally entangled feature maps capable of distinguishing phases of an extended SSH model from random eigenstates using a quantum reservoir-computing benchmark. Technologically, our results harness the power of mid-circuit measurements for realizing quantum advantages on hardware with a favorable topology. Conceptually, we highlight their power in achieving rigorous computational speedups.

Session Selection:

Condensed Matter

Particle and Nuclear Physics / 65

Constraining Neutrino Interaction Uncertainties with the SAND Near Detector at DUNE

Author: Federico Battisti[1]

[1] *Alma Mater Studiorum - Università di Bologna, INFN Bologna*

The Deep Underground Neutrino Experiment (DUNE) is a next-generation experiment designed to achieve unprecedented precision in the study of neutrino flavour oscillations. To minimize systematic uncertainties associated with neutrino flux predictions and interaction cross-sections, DUNE will utilize a sophisticated near detector (ND) complex. Among its three ND subsystems, the System for On-Axis Neutrino Detection (SAND) is positioned permanently on-axis to continuously monitor the beam. SAND integrates a 0.6 T superconducting magnet and an electromagnetic calorimeter composed of lead–scintillating fibres. Its core volume accommodates an innovative liquid argon (LAr) detector and a low-density tracker. A major objective of SAND is to constrain uncertainties in neutrino interactions, where nuclear effects play a critical role. By employing adjustable CH_2 and carbon (C) slabs, SAND enables the statistical subtraction of nuclear contributions, effectively creating a solid hydrogen target. This approach and its potential to enhance systematic precision in DUNE will be presented, as well as a general overview of SAND's capabilities and physics program.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 67

Search for Higgs Boson Decays to Z Gamma Process with ATLAS Partial Run 3 Combined with Full Run 2 Data

Author: Kang LiuNone

The decay $H \to Z\gamma$ is a rare process predicted by the Standard Model that has not yet been individually observed by either ATLAS or CMS. It proceeds through loop diagrams and is therefore highly sensitive to potential effects of new physics. As such, the search for $H \to Z\gamma$ provides an important window into physics beyond the Standard Model.

During Run 3, the ATLAS experiment collected pp collision data at a center-of-mass energy of $\sqrt{s} = 13.6$ TeV, corresponding to an integrated luminosity of 165 fb^{-1} over the years 2022–2024.

Combined with ATLAS full Run 2 dataset, the ATLAS $H \to Z\gamma$ analysis has achieved the most stringent expected sensitivity to date for this rare decay. The observed (expected) signal strength is determined to be $\mu = 1.3^{+0.6}_{-0.5}$ ($\mu = 1.0^{+0.6}_{-0.5}$), corresponding to an observed (expected) significance of 2.5 (1.9) standard deviations.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 68

Search for Long-lived Particles at Future Lepton Colliders Using Leptons and Jets

Author: Xiang ChenNone

Long-lived particles (LLPs) have a clear signature of physics beyond the Standard Model (BSM), characterized by displaced vertex or decay lengths corresponding to lifetimes of nanoseconds or longer. Lepton colliders provide a clean environment for LLP searches. This study employs full simulation data to investigate LLPs produced in Higgs decays via the process e+e−⟶ZH, where each LLP decays into visible final-state particles such as jets, charged leptons, or neutrinos.
This talk focuses on the 2-lepton channels, including both dielectron and dimuon final states, which benefit from low background and precise tracking. Additionally, sensitivity in the hadronic decay mode (LLP->jets) is further improved using machine learning techniques. By combining multiple decay channels, we demonstrate the enhanced potential for LLPs at future lepton colliders. The signal sensitivity for the branching ratio of Higgs decaying into LLPs reaches a state-of-art limit of 1.0×10^{-6} with a statistics of 4×10^{6} Higgs.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 69

The Landscape of Artificial Intelligence in Particle Physics

Author: Huilin Qu[1]

[1] *CERN*

Artificial intelligence has revolutionized the analysis of large-scale data in particle physics, significantly enhancing the discovery potential for new fundamental laws of nature. In this talk, I will survey the rapidly evolving role of AI in particle physics, highlighting recent developments and their impact on collider and non-collider experiments. Future prospects towards a large-scale, general-purpose foundation model tailored for particle physics will also be discussed.

Session Selection:

Particle and Nuclear Physics

Particle and Nuclear Physics / 72

Particle flow in future lepton collider

Author: Fangyi Guo[1]

[1] *IHEP, CAS*

Precision measurements of Higgs, W, and Z bosons at future lepton colliders demand jet energy reconstruction with unprecedented accuracy. The particle flow approach has proven to be an effective method for achieving the required jet energy resolution. We present CyberPFA, a particle flow algorithm specifically optimized for the crystal bar electromagnetic calorimeter (ECAL) in the CEPC reference detector. This innovative calorimeter design combines excellent intrinsic energy resolution with cost efficiency. And CyberPFA firstly makes the PFA compatible with the homogeneous pseudo-high-granularity ECAL. Integrated with the full detector simulation, CyberPFA achieves a 3.8% boson mass resolution for hadronic decays, exceeding the critical 4% threshold required for W/Z separation.

Session Selection:

Particle and Nuclear Physics

Astronomy and Astrophysics / 73

Constraining Dark Photon Dark Matter with Radio Silence from Soliton Mergers around Supermassive Black Holes

Authors: Dorian AmaralNone; Enrico SchiappacasseNone; Hong-Yi ZhangNone

We place the first constraints on the dark matter fraction contained within dark photon solitons using the absence of their predicted radio-frequency signatures, or radio silence, following mergers around galactic supermassive black holes. In these dense astrophysical environments, spiky dark matter density profiles can form that enhance the soliton merger rate. We present a novel and robust estimate of this rate by incorporating both the steepened dark matter profile and the soliton velocity dispersion via the Jeans equation. For galaxies with an initial profile $\rho_{\rm DM} \propto r^{-1}$, we find the total merger rate across redshifts $0 \leq z \leq 4$ to be $\Gamma_{\rm merg}^{\rm TOTAL} < 10^{-7} f_{\rm DM}^2 \,{\rm Mpc}^{-3}\,{\rm day}^{-1}$, where $f_{\rm DM}$ is the solitonic fraction of dark matter. This enhanced rate leads to more major merger events in which the generated soliton has a mass exceeding a critical threshold, leading to its decay via the triggering the parametric resonance phenomenon that produces brief, narrowband, and energetic radio bursts detectable by fast radio burst surveys. Comparing our predictions with the non-observation of such events, we already obtain $f_{\rm DM} < 10^{-1}$ from the first fast radio burst study. This constraint is strengthened to $f_{\rm DM} < 10^{-2}$ from the Parkes HTRU survey, with CHIME projected to tighten this to $f_{\rm DM} < 10^{-3}$. For larger $f_{\rm DM}$, we instead constrain the effective coupling strength between the dark and visible sectors to lie outside $10^{-18}\,{\rm GeV}^{-1} < g < 10^{-8}\,{\rm GeV}^{-1}$ for dark photon masses in the range $10^{-6}\,\mathrm{eV} < m < 10^{-4}\,\mathrm{eV}$. Our results establish astrophysical transients as powerful probes of dark sectors, opening a window onto the detectability of ultralight vector fields.

Session Selection:

Astronomy and Astrophysics

Astronomy and Astrophysics / 74

Astrophysical implications of low-angular momentum flow around black holes

Author: Indu Kalpa Dihingia[1]

[1] *TDLI-SJTU*

Low-angular momentum accretion onto black holes represents distinct differences from the standard disk paradigm, giving rise to transonic flows, standing shocks, and dynamically evolving structures in the near-horizon region. Using advanced general relativistic magnetohydrodynamic (GRMHD) simulations, we investigate the nonlinear behavior and long-term evolution of such flows around rotating black holes. Our results show that shocks in these low-angular momentum regimes can persist, oscillate, and generate variability imprints in the emitted radiation. In particular, we identify unique centi-Hz quasi-periodic oscillations (QPOs) that naturally arise for supermassive black holes, providing a potential observational signature. I will discuss the physical origin of these oscillations, their dependence on black hole spin and magnetic flux distribution, and their implications for interpreting variability from active galactic nuclei (AGNs) and black hole X-ray binary sources (BH-XRBs).

Session Selection:

Astronomy and Astrophysics

Astronomy and Astrophysics / 75

Formulating the Statistical Mechanics of Self-Gravitating Systems

Author: Jun Yan Lau[1]

[1] *Tsung Dao Lee Institute, Shanghai Jiao Tong University*

A probability distribution function is first and foremost a model for a real configuration of particles (stars, electrons, etc). On the other hand, statistical mechanics is a way of modelling a real system by an ensemble of models which all share the same bulk qualities (e.g. internal energy, volume, and number of particles). I present an unbiased method of selecting models for a given configuration of particles. This method is key to describing the statistical mechanics of self-gravitating systems.

Session Selection:

Astronomy and Astrophysics

Astronomy and Astrophysics / 76

Probing Intrinsic Ellipticity in Neutron Star Binaries

Author: Zhiqiang Miao[1]

[1] *TDLI*

Gravitational-wave astronomy has entered the era of precision modeling, where spin precession, tidal effects, and high-order relativistic corrections are routinely included in waveform analyses. Beyond these well-studied ingredients, it is important to assess rarer phenomena that may nevertheless carry profound physical implications. In this talk, I will present a potentially powerful effect—spin–orbit resonance locking in NSBH and BNS inspirals. Such locking can occur if the neutron star has finite ellipticity, arising from, for example, strong internal magnetic fields, a solid quark core, or other exotic structures.
I will discuss the capability of Advanced LIGO and next-generation observatories to detect such extreme events. A detection would have rich physical implications: measuring the ellipticity would provide direct evidence for magnetars in binaries and allow inference of their internal magnetic fields; offering the most precise way to measure the neutron star moment of inertia, which enables stringent constraints on the dense-matter equation of state, unique tests of general relativity (via the I–Love relation), and even test of exotic compact objects (ECOs).

Session Selection:

Astronomy and Astrophysics

Astronomy and Astrophysics / 77

Influence of giant planet dynamics on the orbital architecture of planetary systems

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Giant planets play a crucial role in shaping planetary systems. When formed early, they can dynamically organize surrounding planetesimals, inducing apsidal alignment that suppresses random velocities—even if eccentricities are excited—thereby promoting the growth of inner rocky planets. Under such conditions, giant planets may support, rather than hinder, terrestrial planet formation.
However, when giant planets undergo dynamical instabilities, their impact turns destructive. Radial velocity surveys show that giant planets often have modest eccentricities and are clustered near the snow line, hinting at histories of mutual scattering. In such cases, inward-scattered giants can disrupt or destroy inner systems, potentially explaining the broken resonance chains observed in Kepler super-Earth systems.
These same instabilities are also expected to eject planets into interstellar space, forming free-floating planets (FFPs). While giant planets are traditionally thought to dominate this population, our population synthesis models—calibrated to microlensing surveys and realistic stellar IMFs—suggest otherwise. The FFP population is dominated by Neptune-like planets, due to their abundance around low-mass stars and greater likelihood of being ejected via mutual scattering.
In this talk, I will explore these interconnected processes, focusing on how planetary dynamics shape both bound and unbound planetary orbital architectures.

Session Selection:

Astronomy and Astrophysics

Condensed Matter / 80

Observation of quantum vortex core fractionalization and skyrmion formation in superconductor

One of the fundamental properties of a superconductor is expulsion of magnetic field. The only known exception was when they form a special type of topological defect: quantum vortices, which consist of a core singularity with circulating currents. The London ' s quantization condition implies that there is one core singularity per quantum of magnetic flux in single-component superconductors. Here, we report the first scanning tunneling microscopy observation of quantum vortex core fractionalization on the potassium-terminated surface of the multiband superconductor KFe2As2. The observed splitting of an integer-flux vortex into several fractional vortices results in a disparity between the number of flux quanta and the number of vortex cores. These fractional vortices tend to arrange in chains, and microscopic calculations show that such chains are characterized by a CP2 skyrmionic topological invariant hence constituting a different type of topological defects: superconducting skyrmions. We discovered significant spectroscopy difference between integer and fractional vortices comprising skyrmions.

Session Selection:

Condensed Matter

Condensed Matter / 81

Design, implementation and testing of a Shot Noise Scanning Tunneling Microscopy System

The shot-noise scanning tunneling microscopy (SN-STM) is an emerging breakthrough in scanning probe techniques, achieving unprecedented atomic-scale resolution in shot-noise measurements to directly resolve the effective charge of tunneling carriers. This presentation will first introduce the fundamental physics of shot noise and its unique applications in quantum transport characterization, followed by the key technical hurdles in implementing shot-noise detection in STM systems. I will then detail our hardware design and assembly process, and rigorous performance validation demonstrating 1e and 2e effective charge measurements. Finally, I will present a roadmap for next-generation SN-STM optimization, targeting enhanced sensitivity through cryogenic RF circuit redesign.

Session Selection:

Condensed Matter

Condensed Matter / 82

Topological Phase Manipulation through Light–Matter Coupling in Cavities

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We investigate how quantum fluctuations in cavities can modify the topological properties of materials such as graphene and quantum Hall (QH) systems. First, building on recent theoretical and experimental advances, we analyze the coupling between QH states and cavity modes with both linear and circular polarizations. Using a combination of microscopic and hydrodynamic approaches, we demonstrate that while the quantized Hall conductivity remains robust in topological limits, cavity coupling induces second-order quantum reactance corrections to the AC conductivities and shifts the Kohn mode frequency. Our methods apply broadly to both integer and fractional QH liquids. These results deepen our understanding of the interplay between QH states and cavity quantum fluctuations, with important implications for future research on topological quantum fluids and cavity-induced effect. In parallel, we propose a cavity-based scheme for realizing Haldane model by embedding graphene in a chiral cavity with time-reversal-symmetry breaking. This configuration enables equilibrium valley polarization and leads to photon–valley locking, manifested as an imbalance in cavity photon numbers associated with the valley degrees of freedom. We further show that topological phase transitions by sublattice split can be identified through sign changes in the valley photon number during interband excitations. These findings underscore the remarkable potential of utilizing cavity quantum fluctuations to engineer electronic and photonic properties specific to valleys and topologies, particularly within the realm of strong light-matter coupling.

Particle and Nuclear Physics / 83

Recent Progress of DarkSHINE R&D

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DarkSHINE is a newly proposed fixed-target experiment initiative to search for the invisible decay of Dark Photon via missing energy/momentum signatures, based on the high repetition rate electron beam to be deployed/delivered by the Shanghai High repetition rate XFEL and Extreme light facility (SHINE). The DarkSHINE experiment has recently conducted a series of prototype tests and explored many other new physics models to expand its physics potential. This presentation will elaborate these recent progresses of DarkSHINE experiment.

Session Selection:

Condensed Matter / 84

Braiding Non-Abelian Anyons on Programmable Superconducting Processors

Non-Abelian anyons are exotic quasiparticle excitations hosted by certain topologically-ordered phases of matter. They are the building blocks of topological quantum computing. In this talk, I will first give a brief introduction to non-Abelian anyons and then report two recent experimental quantum digital simulation of braiding non-Abelian anyons on programable superconducting processors. In the first experiment, we prepare the ground states of the toric-code model with twists, and demonstrate that twists behave as Ising anyons, exhibiting the same fusion rules and non-Abelian braiding statistics of the Ising type. They can be explored to encode topological logical qubits and both single- and two-qubit logic gates can be implemented by braiding them. In the second experiment, we exploit efficient quantum circuits to prepare the non-Abelian topologically ordered ground states of the Fibonacci string-net model and demonstrate braidings of Fibonacci anyons featuring universal computational power. In particular, we create two pairs of Fibonacci quasiparticle excitations by acting string operators on the prepared ground states and demonstrate their nontrivial mutual statistics by braiding them with sequences supporting universal single-qubit logic gates.