Bowen Hall, Princeton University

New Frontiers in Quantum Science with Ultra-Pure GaAs

Book of Abstracts

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Achievement of Ultra-High Electron Mobilities in GaAs Quantum Wells

Loren Pfeiffer
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I will provide an overview of the progress made over five decades toward improving electron mobility in GaAs quantum wells, culminating in the achievement of a world-record mobility of 57 million cm²/Vs in 2021. I will discuss the key advances in molecular beam epitaxy, materials purification, and heterostructure design that enabled these results, as well as the remaining challenges that limit further improvements in sample quality. Finally, I will present our recent efforts to address these outstanding issues and explore pathways toward even higher mobilities and cleaner two-dimensional electron systems.

The Art and Hidden Pitfalls of Molecular Beam Epitaxy: From THz Lasers to Polariton Condensates

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Molecular beam epitaxy (MBE) remains the gold standard for fabricating semiconductor quantum structures where atomically precise control of layer composition, thickness, and doping is paramount. This talk opens with a brief overview of our research programs. Selected highlights will be presented, with our THz QCL program — which has produced successive world records in maximum operating temperature [2, 3] — serving as a particularly compelling illustration of how growth precision and reproducibility directly translate into device performance [1].

The second, and central, part of the talk addresses a less frequently discussed topic: the surprisingly subtle and often invisible ways in which crystal quality can be compromised. We revisit several mechanisms identified in our earlier work: the arsenic drag effect, whereby peripheral molecular beams from idling effusion cells are deflected towards the substrate by the arsenic flux, resulting in unintentional doping despite closed shutters [4]; the existence of submicron-diameter current shunts in morphologically perfect heterostructure layers, attributed to floating organic contaminant molecules that locally suppress Al incorporation during barrier growth [5]; Si segregation and its dependence on growth temperature and arsenic overpressure [6]; and the critical importance of accurate, reproducible Al content in AlGaAs for correct device modelling and optimisation [7]. Beyond these published findings, we discuss additional, less well-documented hazards: impurities in the arsenic source material itself, degradation of pyrolytic boron nitride crucibles and the consequences for flux stability and melt contamination, effusion cell design choices and their impact on flux uniformity and transient behavior, and the role of substrate crystalline quality and surface preparation in seeding defects that propagate through thick device stacks. Together, these observations paint a picture of MBE as a discipline where excellence demands vigilance not only in optimizing growth parameters but also in anticipating and eliminating contamination pathways that are, by their very nature, difficult to detect after the fact.

References

[1] Z.R. Wasilewski, *MBE Growth of THz Quantum Cascade Lasers*, in *Molecular Beam Epitaxy: From Research to Mass Production*, M. Henini, Ed., Elsevier, 2012.

[2] A. Khalatpour et al., *High-power portable terahertz laser systems*, Nature Photonics **15**, 16 (2021).

[3] A. Khalatpour et al., *Enhanced operating temperature in terahertz quantum cascade lasers based on direct phonon depopulation*, Appl. Phys. Lett. **122**, 161101 (2023).

[4] Z.R. Wasilewski, S.J. Rolfe, R.A. Wilson, *Contamination in molecular beam epitaxy: the role of arsenic drag effect*, J. Cryst. Growth **175/176**, 1270 (1997).

[5] Z.R. Wasilewski et al., *On the existence of submicron diameter current shunts in morphologically perfect device layers*, J. Cryst. Growth **312**, 926 (2010).

[6] Z.R. Wasilewski, H.C. Liu, M. Buchanan, *Studies of Si segregation in GaAs using current-voltage characteristics of quantum well infrared photodetectors*, J. Vac. Sci. Technol. B **12**, 1273 (1994).

[7] Z.R. Wasilewski et al., *Composition of AlGaAs*, J. Appl. Phys. **81**, 1683 (1997).

High-Density, High-Mobility GaAs Quantum Wells Enabled by Doping-Well Engineering

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High-mobility GaAs quantum wells grown by molecular beam epitaxy provide a premier platform for exploring correlated electron phenomena. While record mobilities have been achieved at moderate electron densities, extending these advances to higher densities remains challenging due to increased remote ionized impurity scattering in conventional modulation-doped heterostructures. I will discuss our recent progress using doping-well structures with ultrathin AlAs cladding layers to achieve electron densities up to 6×10^{11} /cm^2 while maintaining mobilities approaching 20×10^6 cm^2/Vs. Atomic-resolution STEM confirms the intended heterostructure design, and low-temperature transport measurements reveal robust even-denominator fractional quantum Hall states together with numerous bubble phases. These results establish doping-well engineering as a powerful approach for accessing high-density, high-quality two-dimensional electron systems in GaAs.

A Fate of Supersolid Phases: an Exciton Tribute to Ultra-High Purity GaAs

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Universite Cote d'Azur - CNRS

We scrutinize dipolar excitons of GaAs double quantum wells. These are engineered by enforcing that their electron and hole constituents are confined in a distinct layer. We show that ultra-high purity heterostructures allow one to inhibit inelastic scatterings so that exciton wave-functions are coherently dressed by the photon field. Excitons precisely become macroscopically delocalized, as the result of successive emission and absorption of virtual photons.

First, we report experiments where dipolar excitons are confined in nanoscopic lattice potentials. We show that dipolar repulsions stabilize quantum solids at fractional fillings, while photon-mediated delocalization ensures that these collective phases inherit off-diagonal long-range order. Exciton crystals are thus superfluid, providing a concrete implementation of lattice supersolids. In addition, we report a set of experiments where dipolar excitons are studied in a homogeneous 2D confinement. A different super-solid regime is thus accessed, where excitons spontaneously realize self-bound droplets forming a hexagonal lattice at sub-Kelvin temperatures.

[1] C. Lagoin et al., Nature **609**, 485 (2022)
[2] C. Lagoin et al., Nat. Phys. **22**, 66 (2026)

[3] C. Morin et al., arXiv:2512.16509

Collective neutral excitations as sensitive probe for the quality of 2D charge carrier systems in ultra-pure GaAs quantum wells and in moiré systems

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Ultra-clean low-dimensional interacting charge carrier systems are the basis to explore correlated states and phases. We report the observation of very narrow collective intersubband excitations (ISBE) of 2D electron systems (2DESs) with ultra-high mobilities in high quality GaAs quantum well structures. These findings from resonant inelastic light scattering (RILS) experiments are used as tools for exploration of links between transport mobility and collective electron behavior in 2DES of high perfection. We find that the linewidths of collective ISBE modes can be very narrow with values smaller than 80 µeV [1]. Comparison of ISBE measurements from several high-mobility samples exhibits a variation in linewidth of more than a factor of two indicating surprising lack of direct correlation between ISBE linewidth with mobility [1]. ISBE by RILS are discussed as a sensitive probe to characterize the interacting electron systems for fractional quantum Hall effect (FQHE) studies. We demonstrate that on samples with narrowest ISBE, the low-energy collective charge and spin density modes that indicative for exotic FQHE states in the second LL such as the 5/2 states, the 8/3 states among others can be studied [2-5]. Finally, we demonstrate that the methodology can be similarly applied to study collective chare density excitations in 2D moiré systems such as twisted transition metal dichalcogenides such as $tWSe_2$ with low twist angle forming rather flat moiré bands hosting correlated electron states. We particularly demonstrate the emergence of inter- moiré miniband excitations (IMBE) as analog of the well-established ISBE of 2DEGS in GaAs quantum wells [5].
We acknowledge financial by the DFG via the SPP 2244 and grants WU 637/ 7-2 and 8-1.

References

[1] U. Wurstbauer et al. Solid State Communications 400, 115889 (2025).
[2] U. Wurstbauer et al. Phys. Rev. Lett. *110*, *26801* (2013).
[3] U. Wurstbauer et al. Phys. Rev. B, *92, 241407* (2015).
[4] Z. Liu et al. Phys. Rev. Lett. 128, 017401 (2022).
[5] J. Liang et al. Nature 628, 78–83 (2024).
[6] N. Saigal et al. Phys. Rev. Lett. 133, 046902 (2024).

Collective phenomena in non-equilibirum quantum fluids

Daniele Sanvitto
CNR-NANOTEC

Exciton-polaritons provide a unique laboratory to explore collective quantum phenomena in intrinsically driven-dissipative systems. Differently from equilibrium atomic Bose gases, polariton condensates combine strong interactions, optical accessibility and continuous pumping, allowing a direct experimental access to both steady states and dynamical critical behaviour.

In this talk, I will give a compact overview of collective phenomena in exciton-polariton fluids. I will start from condensation in two-dimensional semiconductor microcavities and the emergence of quasi-long-range order compatible with the Berezinskii-Kosterlitz-Thouless scenario. I will then discuss key signatures of non-equilibrium superfluidity, including suppressed scattering, phase rigidity, quantized vortices and the onset of quantum turbulence in driven two-dimensional condensates. The second part will focus on dispersion engineering in patterned planar waveguides, leading to collective phases such as polariton supersolidity. I will conclude with perspectives toward the quantum regime using waveguide nonlinearities and electrically tunable dipolar interactions.

Anyon braiding and bunching in chiral Mach-Zehnder interferometers

David F. Mross

Weizmann Institute of Science

Fractional quantum Hall states host emergent quasiparticles with fractional charge and statistics, which can be revealed in interference experiments. I will introduce the chiral Mach–Zehnder interferometer, in which interfaces between three distinct filling factors define the interference loop. This architecture exhibits fundamental differences from the more common Fabry-Pérot interferometers regarding localized anyons and Coulomb effects. I will present and interpret experimental results from an ultra-high-mobility GaAs heterostructure realizing such an interferometer, which reveal a surprising 'bunching' tendency of anyons.

High mobility 2D semiconductors

Sankar Das Sarma

University of Maryland

Universal Anyon Tunneling in a Chiral Luttinger Liquid

Michael J. Manfra

Purdue University - Microsoft Quantum

The edge modes of fractional quantum Hall liquids are described by chiral Luttinger liquid theory. Despite many years of experimental investigation, fractional quantum Hall edge modes remain enigmatic with significant discrepancies between experimental observations and detailed predictions of chiral Luttinger liquid theory. Here we report measurements of tunneling conductance between counterpropagating edge modes at $\nu=1/3$ across a quantum point contact fabricated on an AlGaAs/GaAs heterostructure designed to promote a sharp confinement potential. We present evidence for tunneling of anyons through a $\nu=1/3$ incompressible liquid that exhibits universal scaling behavior with respect to temperature, source-drain bias, and barrier transmission. For transmission $t > 0.8$, we measured the scaling exponent $g=0.333 \pm 0.005$ averaged over 29 independent data sets, consistent with the scaling dimension $\Delta=g/2=1/6$ for a Laughlin quasiparticle at the edge. When combined with measurements of the fractional charge $e^*=e/3$ and the anyonic braiding phase $\vartheta_a=2\pi/3$, the measured tunneling exponent fully characterizes the topological order of the primary Laughlin state at $\nu=1/3$.

Noise experiments for the characterization of anyons

Gwendal Fève
Sorbonne Universite – Ecole Normale Superieure

I will discuss recent experiments conducted at LPENS and C2N to characterize the properties of elementary excitations in fractional quantum Hall conductors: anyons. High-mobility GaAs-AlGaAs heterostructures enable the realization of various fractional quantum Hall states. By using metallic gates deposited on the surface, we can fabricate tunable partitioner of anyonic currents and investigate the properties of anyons through two-particle interferometry experiments, commonly referred to as noise measurements. Focusing on the fractional quantum Hall state at filling factor 1/3, I will explain how these noise measurements allow us to explore the exotic properties of anyons, including their fractional charge, statistics, and scaling dimension.

40+ Million cm^2/ (V s) Electron Mobility Field-Effect Electronic Devices

Guillaume Gervais
Department of Physics, McGill University

I will discuss our recent advances in the fabrication of field-effect-gated electronic devices based on the latest generation of GaAs/AlGaAs two-dimensional electron gases (2DEGs) grown at Princeton. I will show an alternative device fabrication approach that preserves the exceptionally high electron mobility of these systems, avoiding the detrimental effects often associated with conventional processing techniques.

I will present proof-of-concept results demonstrating successful gating in ultra-high-mobility 2DEGs and compare the advantages and limitations of this approach with those of conventional direct lithography methods. If time permits, I will also discuss recent results obtained in ungated devices related to the v = 5/2 fractional quantum Hall state.

Current induced electron hydrodynamics and extreme phonon emission by supersonic electrons in 2DEGs

Michael Hilke
McGill University

We discuss a striking nonequilibrium regime of transport in an ultrahigh-mobility GaAs/AlGaAs two-dimensional electron gas, where a dc current drives electrons into hydrodynamic flow and ultimately beyond the speed of sound. At low temperatures and small magnetic fields, differential resistivity reveals a rich transport landscape shaped by close to zero resistance, negative magnetoresistance, ballistic effects, and high-order Hall field-induced resistance oscillations. Most dramatically, as the electron drift velocity approaches and exceeds the sound barrier, we observe intense, sharply resonant, temperature independent phonon-induced resistance oscillations, signaling extreme acoustic phonon emission from supersonic electrons in Landau-quantized states [1]. This behavior is qualitatively distinct from the subsonic regime, where low-temperature phonon scattering is strongly suppressed. Our results show that dc current can be used not only to induce hydrodynamic transport, but also to trigger a fundamentally new regime of resonant phonon emission, with a measured strong-regime electronphonon coupling constant of g^2 = 0.0016.

[1] Z. T. Wang and M. Hilke and N. Fong and D. G. Austing and S. A. Studenikin and K. W. West and L. N. Pfeiffer, Phys. Rev. Lett. (2026), https://doi.org/10.1103/m1nb-j1h6

Electron-electron interactions and nonequilibrium electron dynamics in ultrapure GaAs/AlGaAs

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Ultrapure GaAs/AlGaAs heterostructures host 2D electron systems with long electron mean-free paths (order 100 micron at cryogenic temperatures) and low electron momentum dissipation. In mesoscopic structures the materials enable new insights in the hydrodynamic, ballistic, and quantum-coherent electron transport regimes. The locality of electron transport breaks down when electron momentum is mostly not dissipated out of the electron system, as is the case in the ballistic and the hydrodynamic transport regimes. We highlight our experiments in mesoscopic nonlocal geometries, and show the transitions between ballistic, hydrodynamic and diffusive transport regimes. In the hydrodynamic regime, electron-electron interactions lead to viscous behavior with unusual properties such as the formation of current vortices and negative nonlocal resistances. The measurements are paralleled by simulations using the Boltzmann equation, providing maps of current density streamlines and potentials. Besides viscosity, electron-electron interactions determine the fundamental quasiparticle lifetime in a Fermi liquid. We have used ballistic transport as a precise experimental method to quantify electron-electron interactions, finding results consistent with Fermi liquid behavior. Yet the results also indicate a need for distinguishing the actual interaction length scales determining viscosity. To change the electron temperature as distinct from crystal lattice temperature, we performed experiments driving the electron system out of equilibrium, strongly affecting electron-electron interactions. In this regime we demonstrate obligate nonlinearities in the current-voltage relations. The studies advance the understanding of nonequilibrium electron dynamics and quasiparticle lifetimes, yet also form a basis for low-dissipation cryoelectronics for quantum- and sensor technologies.

Low-noise amplification using hydrodynamic charge transport

Manichandra Morampudi
nOhm Devices, Inc.

Low-noise amplification is a central bottleneck for scaling quantum processors: signals generated at millikelvin temperatures are extremely weak, yet conventional cryogenic amplifiers dissipate too much power to be placed close to the qubit plane. In this talk, I will present a new route to deep-cryogenic amplification based on hydrodynamic charge transport in ultra-high-mobility GaAs/AlGaAs devices. In this regime, electron–electron scattering drives collective, fluid-like current flow, producing strong nonlinear input–output response at nanowatt-scale dissipation. I will discuss how these nonlinear transport properties can be engineered for signal gain while minimizing heat load and preserving low-noise operation at the cold stage.

Examining ultra-high mobility 2DES heterostructures for non-Abelian properties

Robert Willet
Nokia Bell Labs

In our long ongoing interferometer measurements we have examined several generations of high-mobility heterostructures for specific non-Abelian signatures with improved manifestation of these properties as mobility has improved. These findings will be summarized here covering non-Abelian even odd effects observed at 5/2 and 7/2 using Fabry-Perot interferometers plus further measurements with these devices in which localized quasiparticle number is specifically adjusted using charging dots within the interferometers. Results at other non-Abelian candidates states will also be described.

Observation of fractional charges via anyon-trions

Xiaodong Xu
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Fractionalization of the electron charge is one of the most striking phenomena arising from strong electron-electron interactions. A celebrated example is the emergence of anyons with fractionally charged excitations in fractional quantum Hall effect (FQH) states. Recently, fractional quantum anomalous Hall effect (FQAH), a lattice analog of the FQH realized at zero magnetic field, has been demonstrated (1). FQAH provides a unique platform to investigate anyons, yet their detection remains a challenge. In this talk, I will first present transport measurements that establish FQAH in twisted MoTe2 bilayer (1-2). I will then show how ~1 eV photons can be used to probe fractional excitations that are three orders of magnitude lower in energy (3). The results include observation of an abundant Jain sequence of fractional states and a new type of quasi-particle complex, anyon-trions (4). Observation of the FQAH and associated phenomena pave the way for exploring charge fractionalization and anyonic physics at zero magnetic field.

[1] Observation of Fractionally Quantized Anomalous Hall Effect, Heonjoon Park, et al, Nature 622, 74 (2023;
[2] Observation of dissipationless fractional Chern insulator, Heonjoon Park, et al, Nature Physics https://doi.org/10.1038/s41567-025-03167-2 (2026).
[3] Signatures of Fractional Quantum Anomalous Hall States in Twisted MoTe2 Bilayer, Jiaqi Cai et al, Nature 622, 63 (2023);
[4] Signatures of fractional charges via anyon–trions in twisted MoTe2, Weijie Li et al, Nature https://doi.org/10.1038/s41586-026-10101-w (2026)

Canonical effects of Bose-Einstein condensation of polaritons in GaAs/AlGaAs structures

David Snoke
University of Pittsburgh

The quality of experimental results with polariton Bose condensates has steadily increased in the past 20 years, in part because of the development of polariton microcavity structures with cavity lifetime long enough to allow polaritons to reach thermal equilibrium. I will discuss the design considerations for these structures, and review the experimental methods and results showing persistent circulation, Bogoliubov linear excitation branches, and onset of coherence after a quench.

Towards Quantum Reservoir Computing with Polaritons

Andrew Haky
Laboratoire Kastler Brossel, Sorbonne University, CNRS, ENS-PSL Research University

Extraordinary control over the growth of GaAs heterostructures has enabled low loss rates and extremely high nonlinearities, making microcavity polaritons an attractive platform for quantum optics. While the regime of strongly correlated polaritons remains difficult to access, recent theoretical work suggests that exciton-polaritons may already be ideal for realizing a reservoir computing architecture capable of quantum state recognition.

Toward this aim, we have begun pursuing a novel approach to study the interaction of microcavity polaritons with quantum states of light, using thermal squeezed states. The use of these states allows us to study the same polariton dynamics expected under excitation by nonclassical states with noise below the standard quantum limit, while alleviating the strict experimental constraint of avoiding all losses.

We will report the first results from an experiment in which we quasi-resonantly inject these states into planar GaAs microcavity polaritons. We find the polariton nonlinearity redistributes and amplifies noise between field quadratures, suggesting that the quantum properties of the light could be transferred to another more accessible observable.

Different Phases of Polariton Condensates

Hui Deng
University of Michigan

We will discuss phase separation in a polariton condensate, between a quasi-BEC without long-range order and a BKT-like phase with quasi-long range order, due to the interplay of nonlinearity and pumping, thermalization and decay.

Room-Temperature Strong Coupling and Lower-to-Upper Polariton Condensation Switching in GaAs/AlGaAs Microcavities

Hassan Alnatah
Joint Quantum Institute, University of Maryland

We present an experimental demonstration of chiral spin selectivity in the strong coupling between the electromagnetic mode of a semiconductor microcavity and an electronic transition in a hole-doped GaAs quantum well. To achieve this, we exploit the exotic properties of a 2D hole gas confined to a quantum well when operating in the quantum Hall regime. For a high charge density, we demonstrate how the manipulation of the filling factor (defined as the ratio between the charge density and the density of states) through an external magnetic field B, leads to an imbalance in the population of each spin band, which in turn manifests as a selective strong coupling that can be probed through the circular degree of polarization of the exciting light.

Ref: Nature Photonics 17, 912-916 (2023).

GaAs adventures with Loren Pfeiffer: a 30 years perspective on our joint work on excitons and polaritons

Ronen Rapaport
The Racah Institute of Physics, The Hebrew University of Jerusalem

I will give a short review on a collaborative research that started during my PhD, and lasted continuously until this day. I will bring up a few highlights such as the first observation of Charged (or polaron) exciton polaritons, the mystery of exciton rings, the first electrostatic traps and transporters of dipolar (interlayer, indirect) excitons, and observations of exotic collective effects such as dynamical dark-spin exciton condensation and attractive dipolarons.

Finally, I'll bring up a few new results and future perspectives on strongly nonlinear dipolar exciton polariton quantum circuits and open questions to explore.

Hexagonal Synthetic Josephson Junction Lattices on epitaxial Al-InAs

Javad Shabani
NYU

Josephson junction arrays have a rich history of both theoretical and experimental exploration. Vortex dynamics and phase transitions have been studied in one dimensional and two-dimensional arrays of various geometries. Additionally, Josephson junction arrays have been used for quantum simulation, where the coupling between superconducting islands and the structure of the lattice can be engineered to emulate a specific Hamiltonian. Very recently Josephson junction arrays based on superconductor - semiconductor junctions have been proposed to be a platform for studying chiral topological superconductivity. With controlled modulation of the inter-island Josephson couplings, engineered phase winding, and the application of an in-plane exchange field, these systems can be driven into a two-dimensional topological superconducting-phase.

Here we report measurements of arrays of planar superconductor (Al) - semiconductor (InAs) Josephson junctions designed in square and hexagonal lattices. We study the critical current magnitude as a function of magnetic field perpendicular to the plane of the array and connect this to the expected vortex configurations in the lattice. In addition, we study the dependence of the critical current as a function of in-plane magnetic field magnitude at finite perpendicular magnetic field. We report a minimum in the critical current uniquely for the hexagonal geometry and discuss possible interpretations of the data.

MBE Growth, properties and applications of unstrained GaAs/AlGaAs quantum dots

Armando. Rastelli
Linz University, Austria

Optically active semiconductor quantum dots (QDs) keep attracting much interest as bright sources of indistinguishable and entangles photons as well as hosts of spins for potential applications in emerging quantum technologies. The best optical properties are obtained by relying on self-assembly of nanostructures during molecular beam epitaxy (MBE). While most pioneering works have been accomplished with strained InGaAs QDs obtained via the so-called Stranski-Krastanow growth mode, these QDs are usually characterized by alloy disorder, which affect the ensemble homogeneities and coherence time of confined spins.

In this talk we will discuss the MBE growth of quasi-unstrained GaAs QDs obtained by filling of self-assembled nanoholes on an AlGaAs surface, their properties, and potential applications. In particular, by using the local droplet etching method for the fabrication of nanoholes, it is possible to obtain QDs that are characterized by small inhomogeneous broadening, high oscillator strengths, shape with high in-plane symmetry, and high optical quality. These properties make them particularly suited for the generation of polarization-entangled photon pairs. To make sure the QDs fulfil simultaneously criteria of maximal brightness, desired emission wavelength and charge state, it is necessary to integrate them in photonic devices, which ideally should display a high degree of tunability. To address this challenge, we have recently introduced strain- and electrically-tunable sources of highly entangled photon pairs and indistinguishable single photons based on a diode-circular-Bragg-gratings resonator with deterministically embedded QDs. Progress and challenges will be discussed.

Strongly interacting composite fermions in ultra-high-quality GaAs 2D hole systems

Chengyu Wang
Princeton University

The fractional quantum Hall effect is commonly understood in terms of weakly interacting composite fermions (CFs), whose integer quantum Hall states account for the vast majority of observed odd-denominator fractional quantum Hall states (FQHSs). Under suitable conditions, however, residual interaction between CFs can become sufficiently strong, leading to new correlated many-body phases beyond the standard CF paradigm. In this talk, I will present recent experiments on ultra-high-quality GaAs two-dimensional hole systems that reveal several manifestations of strong CF-CF interaction.

First, I will discuss the observation of a new generation of even-denominator FQHSs in the lowest Landau level (LL). These include FQHSs at v = 3/4, 3/8, and 3/10, which can be understood as paired states of CFs in half-filled excited (N_{CF} = 1) CF Λ levels. I will also discuss the emergence of FQHSs at extremely small fillings v = 1/4 and 1/6, which are naturally interpreted as paired states of four-flux and six-flux CFs, respectively. Taken together, these observations point to unusually strong residual interaction among CFs in the presence of severe LL mixing.

I will then present the observation of an exotic stripe-nematic phase at v = 5/8, deep in the fractional quantum Hall regime. Remarkably, v = 5/8 maps to a half-filled excited Λ level of CFs (v_{CF} = 5/2, N_{CF} = 2), analogous to the high-orbital-index electron/hole LLs where stripe-nematic phases are seen near half fillings. Unlike conventional electronic stripe-nematic phases, however, this phase emerges in the lowest LL and is best understood as a stripe-nematic phase of CFs driven by enhanced residual CF-CF interactions.

Together, these results demonstrate that ultra-high-quality GaAs hole systems provide a unique platform for exploring pairing and stripe formation among CFs, revealing a rich landscape of strongly correlated phases beyond the conventional picture of weakly interacting Cfs.

Toward high-order nonabelions: formation of helical states in the fractional quantum Hall regime

Leonid Rokhinson
Purdue University

I will describe our effort to built a platform to realize highorder non-Abelian excitations based on helical domain walls formed in the fractional quantum Hall regime. Domain walls in fractional quantum Hall ferromagnets are gapless helical one-dimensional channels formed at the boundaries of topologically distinct quantum Hall (QH) liquids. Naively, these helical domain walls (hDWs) constitute two counter-propagating chiral states with opposite spins. Coupled to an s-wave superconductor, helical channels are expected to lead to topological superconductivity with high order non-Abelian excitations. Experimental investigation of a transport through a single hDWs in the v=2/3 fractional QH regime is found to be substantially smaller than the prediction of the naive model. Luttinger liquid theory of the system reveals redistribution of currents between quasiparticle charge, spin and neutral modes, and predicts the reduction of the hDW current. Inclusion of spin-non-conserving tunneling processes reconciles theory with experiment. The theory confirms emergence of spin modes required for the formation of fractional topological superconductivity

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New Ground States with Complex Order in Ultra-High Mobility GaAs at Ultra-Low Temperatures

Gabor Csáthy
Department of Physics and Astronomy - Purdue University

Recent substantial increase in the quality of GaAs/AlGaAs quantum wells provided an opportunity to look for new ground states in the ultra-low temperature regime. In this talk I will highlight the observation of ground states in GaAs/AlGaAs so far not seen in any other high quality two-dimensional platforms, such as BN-incapsulated graphene or ZnO/MgZnO. In particular, I will discuss two recent experimental findings: a) the fully gapped fractional quantum Hall state at n=9/11, which can be associated with the formation of six-flux composite fermions b) a fractional quantum Hall state beyond the standard Jain sequence at n=7/11, and c) the observation of the reentrant fractional quantum Hall effect, which is associated with the formation of a bubble phase of composite fermions.

Two-component fractional quantum Hall states in an ultrapure GaAs quantum well

Michael Zudov
University of Minnesota

While two-component fractional quantum Hall (2C-FQH) states have been known for decades, their experimental realization remained limited to low-order fractions. Here we report on several families of high-order 2C-FQH states [1] that emerge when an in-plane magnetic field induces a monolayer-to-bilayer transition in an ultra-pure GaAs quantum well. These states proliferate symmetrically toward the filling factor v = 1, from both v = 2/3 and v = 4/3, respecting particle-hole symmetry. Surprisingly, many states with unequal layer fillings are more robust than their parent balanced states, defying the expected hierarchy of Jain sequences. We also observed 2C-FQH states involving inter-layer correlations, at v = 3/2, 19/13, and 41/29 [2], which emerge under similar experimental conditions. These findings substantially expand the known landscape of 2C-FQH states, highlighting the richness of the bilayer quantum Hall regime and opening avenues for probing the interplay of symmetry, topology, and interactions in quantum Hall systems.

[1] E. Bell, K. W. Baldwin, L. N. Pfeiffer, K. W. West, and M. A. Zudov, High-order two-component fractional quantum Hall states around filling factor ν = 1, https://arxiv.org/abs/2512.04050.
[2] V. W. Scarola and J. K. Jain, Phase diagram of bilayer composite fermion states, Phys. Rev. B 64, 085313 (2001)

Chiral light-matter coupling in a 2D hole gas-microcavity system in the Quantum Hall regime

Daniel G. Suárez-Forero
University of Maryland, Baltimore County

We present an experimental demonstration of chiral spin selectivity in the strong coupling between the electromagnetic mode of a semiconductor microcavity and an electronic transition in a hole-doped GaAs quantum well. To achieve this, we exploit the exotic properties of a 2D hole gas confined to a quantum well when operating in the quantum Hall regime. For a high charge density, we demonstrate how the manipulation of the filling factor (defined as the ratio between the charge density and the density of states) through an external magnetic field B, leads to an imbalance in the population of each spin band, which in turn manifests as a selective strong coupling that can be probed through the circular degree of polarization of the exciting light.

Ref: Nature Photonics 17, 912-916 (2023).