NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

EPQHS-9

SINGAPORE

2024

The 9th International Workshop on
Emergent Phenomena in Quantum Hall Systems

Jan 3 - Jan 5, 2024

21 Nanyang Link,
Singapore 637371

Designed by Yuzhu Wang. Published and distributed by School of Physical and Mathematical Sciences, Nanyang Technological University.
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The Singapore emergency ambulance and fire emergency number is **995**, and the police emergency number is **999**.

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- **SG Arrival Card (SGAC).** All travelers are required to submit the **SG Arrival Card (SGAC)** within three days (including the day of arrival) before arrival in Singapore. To avoid unnecessary delays during immigration clearance upon your arrival, we strongly advise the participants to submit the SG Arrival Card **within three days (including the day of your arrival)** before your arrival in Singapore. The website is:

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- **Leaving the Airport.** We suggest that the participants take taxis to leave the airport, which can be reimbursed by the organizers. Taxis are available for hire at the taxi stands in the Arrival areas of Terminals 1, 2, 3, and 4. A ride to the city takes about 30 minutes and costs between S$20 and S$40. All fares are metered.

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- **Park Avenue Rochester** (Near Buona Vista. Around 25-min drive to SPMS.)
  Address: 31 Rochester Dr, Singapore 138637
  Phone: +65 6808 8600
- **Genting Hotel Jurong** (Near Jurong East. Around 18-min drive to SPMS.)
  Address: 2 Town Hall Link, Singapore 608516
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Shuttle bus schedule

Shuttle buses will be provided between SPMS and two hotels (Park Avenue Rochester and Genting Hotel Jurong). There will be bus captains (Yuzhu Wang and Guangyue Ji) to guide the participants. **Please note that the bus to the hotels will be from Tan Chin Tuan Lecture Theater on Jan 4.**

Bus List			
	Jan 3rd	Jan 4th	Jan 5th
Morning bus from the hotels	8:00:00 AM**	8:20:00 AM**	8:20:00 AM**
Evening bus from NTU to hotels	6:00:00 PM**	7:00:00 PM*	N/A
Afternoon bus from NTU to banquet	N/A	7:00:00 PM*	N/A
Evening bus from banquet restaurant to hotels	N/A	9:40:00 PM*	N/A

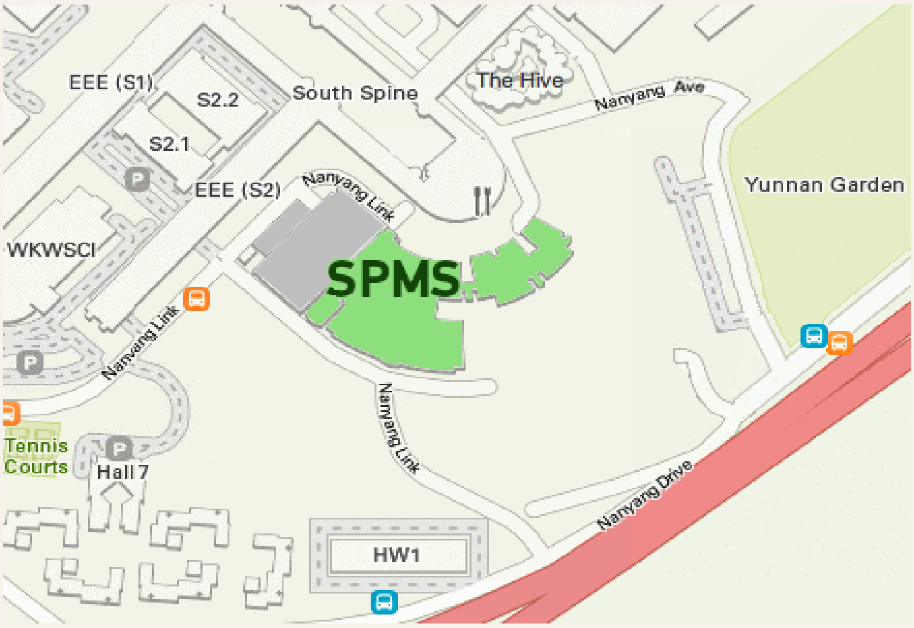
* One bus to two hotels.
** Two different buses to two hotels.

During the Workshop

- The workshop venue is:
  School of Physical and Mathematical Sciences
  Nanyang Technological University
  21 Nanyang Link
  Singapore 637371

After arriving at the lobby, one can take the lift to the third floor and turn left. Follow the signs to **the Atrium**, where a workshop reception can be found.

- Tea breaks and lunches will be provided during the workshop.



Position of SPMS. The main gate is on Nanyang Link, where the shuttle buses will stop.

Official website

More information, such as programs and speakers, can be found on our official website: `https://web.spms.ntu.edu.sg/~epqhs-9/index.html`, or by simply scanning the QR code below:

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SESSIONS

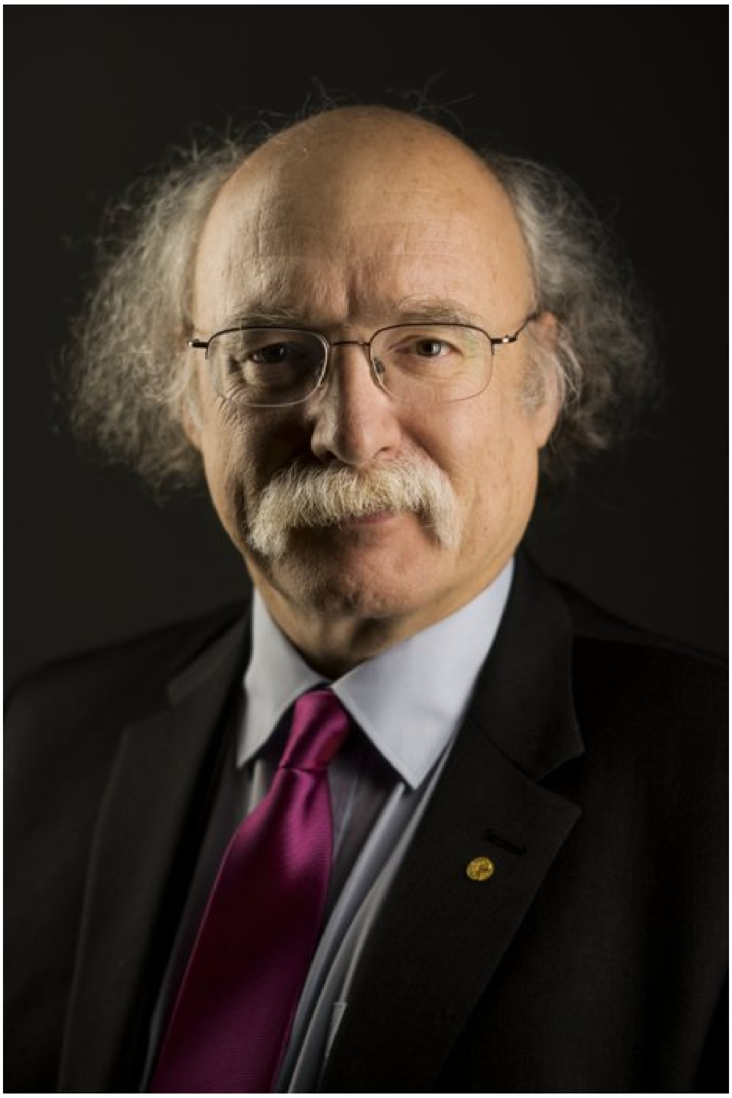
"Let us hold our discussion together in our own persons, making trial of the truth and of ourselves."

—Protagoras

Part 1

Invited Speakers

Klaus von Klitzing is a German physicist, who is heading the department ”Low Dimensional Electron Systems” at the Max Planck Institute for Solid State Research in Stuttgart, Germany, known for the discovery of the integer quantum Hall effect, for which he was awarded the 1985 Nobel Prize in Physics.



Frederick Duncan Michael Haldane is a British-born physicist who is currently the Sherman Fairchild University Professor of Physics at Princeton University. He is a co-recipient of the 2016 Nobel Prize in Physics, along with David J. Thouless and J. Michael Kosterlitz.

Bertrand I. Halperin is an American physicist, former holder of the Hollis Chair of Mathematicks and Natural Philosophy at the physics department of Harvard University. He was awarded the Oliver E. Buckley Condensed Matter Prize in 1982, the Lars Onsager Prize in 2001, the Wolf Prize in Physics in 2003, and the APS Medal for Exceptional Achievement in Research in 2019, for his seminal contributions to theoretical condensed matter physics, especially his pioneering work on the role of topology in both classical and quantum systems.

Part 2

Abstracts

Electric Quadrupole Density and Quantum Geometry in the Quantum Hall Effect

Speaker: F. Duncan M. Haldane (Princeton University)

Time: 9:00 am - 9:35 am, Jan 3rd.

The geometry of the quantum Hall effect (both integer and fractional) is characterized by a primitive (as opposed to “traceless”) electric quadrupole density which, in the FQHE is associated with “flux attachment”, and is the shape of the “composite boson”, the elementary unit of the incompressible fluid. The Hall viscosity tensor can be expressed in terms of it, and the gapped collective (GMP) mode has quadrupolar fluctuation dynamics, and can be viewed as an emergent degree of freedom analogous to a Goldstone mode (gapped because no symmetry is broken) that appears when “flux attachment” occurs.

Reference: F. D. M. Haldane, arXiv:2302.1242.

A new generation of even-denominator fractional quantum Hall states in a new generation of ultrahigh-quality 2D systems

Speaker: Mansour Shayegan (Department of Electrical and Computer Engineering, Princeton University)

Time: 9:35 am - 10:10 am, Jan 3rd.

We present our latest experimental results on magnetotransport measurements in new ultrahigh-quality GaAs/AlAs samples. These samples contain exceptionally low levels of disorder. They are among the purest solid-state materials, with the residual impurity concentration well below 1 part per 10 billion atoms, and exhibit low-temperature 2D carrier mobilities up to about 60×10^6 cm^2/Vs [1-4]. The samples reveal the emergence of new phenomena, dominated by electron-electron interaction. In this talk I will focus on numerous even-denominator fractional quantum Hall states we observe in the lowest (N = 0) Landau level in different 2D carrier systems, electrons or holes in GaAs, and electrons in AlAs [5-10].

References:

1. Yoon Jang Chung, K. A. Villegas-Rosales, K. W. Baldwin, P. T. Madathil, K. W. West, M. Shayegan, and L. N. Pfeiffer, ”Ultra-high-quality Two-dimensional Electron Systems,” Nature Materials 20, 632 (2021).
2. Yoon Jang Chung, C. Wang, S. K. Singh, A. Gupta, K. W. Baldwin, K. West, M. Shayegan, L. N. Pfeiffer, and R. Winkler, ”Record-quality GaAs two-dimensional hole systems,” Phys. Review Materials 6, 034005 (2022).
3. Yoon Jang Chung, A. Gupta, K. W. Baldwin, K. W. West, M. Shayegan, and L. N. Pfeiffer ”Understanding limits to mobility in ultra-high-mobility GaAs two-dimensional electron systems: The quest for 100 million cm^2/Vs and beyond,” Phys. Rev. B 106, 075134 (2022).
4. Adbhut Gupta, C. Wang, S.K. Singh, K.W. Baldwin, R. Winkler, M. Shayegan, and L.N. Pfeiffer, ”Ultraclean two-dimensional hole systems with mobilities exceeding 10^7 cm^2/Vs,” submitted for publication (2023).
5. Chengyu Wang, A. Gupta, S. K. Singh, Y. J. Chung, L. N. Pfeiffer, K. W. West, K. W. Baldwin, R. Winkler, and M. Shayegan, ”Even-denominator fractional quantum Hall state at filling factor $v = 3/4$,” Phys. Rev. Lett. 129, 156801 (2022).
6. Md. Shafayat Hossain, Meng K. Ma, Y. J. Chung, S.K. Singh, A. Gupta, K. W. West, K. W. Baldwin, L. N. Pfeiffer, R. Winkler, M. Shayegan, ”Valley-tunable even-denominator fractional quantum Hall state in the lowest Landau level of an anisotropic system,” Phys. Rev. Lett. 130, 126301 (2023).
7. Chengyu Wang, A. Gupta, Y. J. Chung, L. N. Pfeiffer, K. W. West, K. W. Baldwin, R. Winkler, and M. Shayegan, ”Highly-anisotropic Even-denominator Fractional Quantum Hall State in an Orbitally-coupled Halffilled Landau Level,” Phys. Rev. Lett. 131, 056302 (2023).
8. Chengyu Wang, A. Gupta, P. T. Madathil, S. K. Singh, Y. J. Chung, L. N. Pfeiffer, K. W. Baldwin, and M. Shayegan, ”Next-generation even-denominator fractional quantum Hall states of interacting composite fermions,” Proc. National Acad. Sciences (PNAS) (2023); in press.
9. Chengyu Wang, A. Gupta, S. K. Singh, P. T. Madathil, Y. J. Chung, L. N. Pfeiffer, K. W. Baldwin, R. Winkler, and M. Shayegan, ”Fractional Quantum Hall State at Filling Factor $v = 1/4$ in Ultra-high-quality GaAs 2D Hole Systems,” Phys. Rev. Lett. (2023); in press.
10. Siddharth Kumar Singh, C. Wang, C. T. Tai, C. S. Calhoun, A. Gupta, K. W. Baldwin, L. N. Pfeiffer, and M. Shayegan, ”Topological phase transition between Jain states and daughter states of the $v = 1/2$FQHS,” submitted for publication (2023); cond-mat arXiv: 2309.00111.

Kekule Spirals in Twisted Multilayer Graphene

Speaker: Steven H. Simon (Oxford University)

Time: 10:10 am - 10:45 am, Jan 3rd.

Magic angle twisted bilayer graphene has emerged as one of the most exciting new experimental systems, displaying a wealth of exciting physics from superconductivity to anomalous quantized Hall effect.

We focus on temperatures above the superconducting transitions and predict a new phase of matter, the incommensurate Kekule Spiral phase, that we believe arises ubiquitously in the presence of tiny amounts of strain [1,2,3]. Recent experiments have now unambiguously confirmed these predictions [4]. I will describe this phase of matter and explain why it arises. Similar physics has also been observed [5] in symmetric twisted trilayer graphene as well, and I will discuss the related theory of this phase as well [6].

References:

1. Yves H. Kwan, Glenn Wagner, Tomohiro Soejima, Michael P. Zaletel, Steven H. Simon, S. A. Parameswaran, Nick Bultinck, Phys. Rev. X 11, 041063 (2021),
2. Glenn Wagner, Yves H. Kwan, Nick Bultinck, Steven H. Simon, S. A. Parameswaran, Phys. Rev. Lett. 128, 156401 (2022).
3. Yves H. Kwan, Glenn Wagner, Nick Bultinck, Steven H. Simon, Erez Berg, S. A. Parameswaran, arXiv:2303.13602.
4. K. P. Nuckolls et al, Nature 620, 525-532 (2023).
5. H. Kim et al, Nature 623, 942–948 (2023).
6. Ziwei Wang, Yves H. Kwan, Glenn Wagner, Nick Bultinck, Steven H. Simon, S. A. Parameswaran, arXiv:2310.16094.

Towards Bosonic Fractional Quantum Hall Effect in a Moat Band

Speaker: Rui Rui Du (Peking University)

Time: 11:00 am - 11:35 am, Jan 3rd.

Correlation and frustration play essential roles in physics, giving rise to novel quantum phases. A typical frustrated system is correlated bosons on moat bands, which could host topological orders with long-range quantum entanglement. However, the realization of moat-band physics is still challenging. Here, we explore moat-band phenomena in shallowly inverted InAs/GaSb quantum wells, where we observe an unconventional time-reversal-symmetry breaking excitonic ground state under imbalanced electron and hole densities. Theoretically, we show that strong frustration from density imbalance leads to a moat band for excitons, resulting in a time-reversal-symmetry breaking excitonic topological order, which explains all our experimental observations. More recently, by new experiments we have confirmed the moat band physics in strongly spin-orbit coupled InAs/GaSb quantum wells. These developments open a new direction for realizing bosonic fractional quantum Hall effects in the presence of zero magnetic field.

Reference: R. Wang, T. A. Sedrakyan, B. G. Wang, L. J. Du, R. R. Du, Excitonic topological order in imbalanced electron–hole bilayers. Nature 619, 57–62 (2023).

3D Quantum Hall Effect

Speaker: Hai-zhou Lu (Southern University of Science and Technology)

Time: 11:35 am - 12:10 pm, Jan 3rd.

The quantum Hall effect is usually observed in 2D. It has been a long-standing challenge to realize a quantum Hall effect in 3D. We predict a new mechanism of 3D quantum Hall effect in topological semimetals [1-3]. Topological semimetals host topologically-protected surface states, known as the Fermi arc, which is a half 2D electron gas. The Fermi arcs on two opposite surfaces can form a complete 2D electron gas that supports a 3D quantum Hall effect. Possible signatures are observed in the topological Dirac semimetal Cd_3As_2 [e.g., Faxian Xiu et al., Nature 565, 331 (2019)]. This 3D quantum Hall effect gives an example of the 2nd-order topological insulator, which could be driven to the 1st-order topological or normal insulator by the Coulomb interaction [4].

Later, the charge-density-wave (CDW) mechanism of the 3D quantum Hall effect has been observed in $ZrTe_5$ [Liyuan Zhang et al., Nature 569, 537 (2019)]. We develop a theory for the CDW 3D quantum Hall effect [5] and coexisting metal-insulator transition [6]. The theories can capture the main features in the experiment and show the dominance of electron-phonon interactions in the phase trasitions. More importantly, it is a rare case, in which a magnetic field can drive an order-parameter phase transition in one dimension while a topological phase transition in other two dimensions.

References:

1. C. M. Wang et al., PRL 119, 136806 (2017).
2. Hai-Zhou Lu, National Science Review 6, 208 (2019).
3. Rui Chen et al., PRL 127, 066801 (2021).
4. Peng-Lu Zhao et al., PRL 127, 176601 (2021).
5. Fang Qin et al., PRL 125, 206601 (2020).
6. Peng-Lu Zhao et al., PRL 127, 046602 (2021).

Towards Dissipationless Topotronics

Speaker: Xincheng Xie (Peking University)

Time: 12:10 pm - 12:45 pm, Jan 3rd.

Electrical charge transport in traditional nanoscale integrated circuits is always accompanied by energy dissipation in the form of Joule heating, which imposes a thermal bottleneck constraining their performance. The emergence of novel topological systems opens up exciting avenues for optimizing thermal management based on the intuitive concept of "no backscattering, no dissipation". However, whether energy dissipation can emerge without backscattering inside topological systems remains a question. In this work, we propose a microscopic picture that illustrates energy dissipation in the quantum Hall plateau regime of graphene. Despite the quantization of Hall, longitudinal, and two-probe resistances, we find that the energy dissipation emerges in the form of Joule heat.

In practice, such energy dissipation phenomenon is universal in topological devices, which casts doubt upon whether it is possible to reach truly dissipationless in topotronics. We propose a criterion for judging whether energy dissipation occurs inside a topological device. This criterion establishes a concise algebraic relationship among the number of modes engaged in transport, $N_{\mathrm{in}} = N_{\mathrm{tunl}} + N_{\mathrm{bs}}$. We advocate for the indispensability of Chern insulators with higher Chern numbers to achieve functional devices and uphold the no-dissipation rule simultaneously. Our work holds promise for shaping the future of integrated topological circuit designs towards no dissipation.

Ferromagnetism, Intervalley Coherence, and Spin-Orbit Coupling in Rhombohedral Trilayer Graphene

Speaker: Trevor Arp (University of California Santa Barbara)

Time: 1:55 pm - 2:30 pm, Jan 3rd.

Rhombohedral graphene is a clean and reproducible system with a van Hove singularity that can be turned with applied perpendicular displacement field. The resulting flat bands are known to host strongly interacting electronic phases with magnetism and superconductivity. [1-5] Using a capacitance circuit to measure inverse compressibility and nanoSQUID on Tip (nSOT) microscopy to measure magnetic field, I will show a rich phase diagram of iso-spin polarized phases in ABC stacked trilayer graphene which arise from the spontaneous breaking of spin and valley symmetries. In particular, I will focus on the "Quarter Metal" regime where an orbitally magnetized valley imbalanced phase competes with an intervalley coherent phase, wherein electron wave functions in the two momentum space valleys develop a macroscopically coherent relative phase. Furthermore, examining the in-plane and out-of-plane magnetic susceptibility reveals the influence of intrinsic spin-orbit coupling in graphene which, with a strength of $\lambda \approx 40\mu\mathrm{eV}$, is non-negligible contribution to the free energy. Spin-orbit coupling is thus an important factor in understanding the interacting electron ground state, and has implications for the spin-triplet superconductivity observed in Rhombohedral graphene.

References:

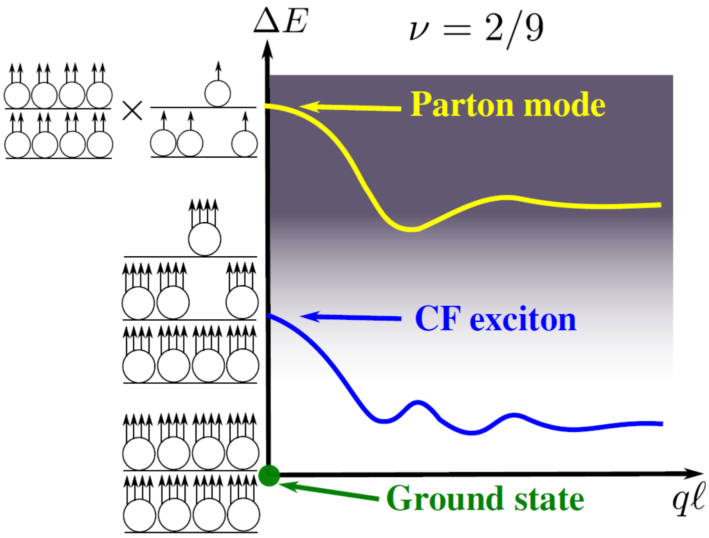
1. H. Zhou, T. Xie, A. Ghazaryan, et al. Nature 598, 429–433 (2021).
2. Zhou, H., Xie, T., Taniguchi, T. et al. Nature 598, 434–438 (2021).
3. Zhang, Y., Polski, R., Thomson, A. et al. Nature 613, 268–273 (2023).
4. H. Zhou, L. Holleis, Y. Saito et al. Science 375, 774-778 (2022).
5. L. Holleis, C. L. Patterson, Y. Zhang et al. arXiv:2303.00742 (2023).

Very-High-Energy Collective States of Partons in Fractional Quantum Hall Liquids

Speaker: Ajit C. Balram (Institute of Mathematical Sciences, CIT Campus; Homi Bhabha National Institute, Training School Complex)

Time: 2:30 pm - 3:05 pm Jan 3rd.

The low-energy physics of fractional quantum Hall (FQH) states - a paradigm of strongly correlated topological phases of matter - to a large extent is captured by weakly interacting quasiparticles known as composite fermions. Here, based on numerical simulations and effective field theory, we argue that some high energy states in the FQH spectra necessitate a different description based on parton quasiparticles. We show that Jain states at filling factor $\nu = \mathrm{n}/(2\mathrm{pn} \pm 1)$ with integers $\mathrm{n}, \mathrm{p} \geq 2$ support two kinds of collective modes: In addition to the well-known Girvin-MacDonald-Platzman (GMP) mode, they host a high-energy collective mode, which we interpret as the GMP mode of partons. We construct a microscopic wave function for the parton mode and demonstrate agreement between its variational energy and exact diagonalization. Our results point to partons being "real" quasiparticles which, in a way reminiscent of quarks, become observable only at sufficiently high energies.



Schematic representation of the spin-2 collective modes of the $v = 2/9$ Jain state.

Reference: Ajit C. Balram, Zhao Liu, Andrey Gromov, and Zlatko Papić. Phys. Rev. X 12, 021008(2022).

Verification of 3/2 Plateau with a Global Gate and Density Control through Gates

Speaker: Xi Lin (Peking University)

Time: 3:05 pm - 3:40 pm, Jan 3rd.

A 3/2 fractional quantum Hall plateau in a regular two-dimensional electron gas with gate confinement at a bulk filling factor of 5/3 has been reported in 2019. The plateau is explained by assuming a surprisingly larger filling factor in the confined region than that of the bulk region in 2023. Within the simple explanation of density mismatch, other observed plateaus such as 9/4, 17/11 and 16/13 can also be understood. We induce a similar 3/2 plateau with only a global gate without a confined region and are investigating the effect of density control through gates.

Anyonic Interference and Braiding in a Mach-Zehnder Interferometer

Speaker: Hemanta-Kumar Kundu (Weizmann Institute)

Time: 3:55 pm - 4:30 pm, Jan 3rd.

Fractional quantum Hall states, which can have either abelian or non-abelian characters, harbor quasiparticles with fractional charges. The quasiparticles' charge is customarily determined via shot noise measurements, while appropriate interference experiments can reveal their quantum statistics. The multipath Fabry-Perot Interferometer is easy to fabricate but is often plagued by Coulomb interaction, area breathing with the magnetic field, and fluctuating bulk charges. I will describe our recent studies with a two-path Mach-Zehnder Interferometer tuned to bulk filling 2/5. Interfering the outermost 1/3 mode (with the inner 1/15 mode screening the bulk) with a partitioned charge $e/3$, we observed a 'Dressed Aharonov-Bohm (AB)' periodicity. The periodicity combined the 'bare AB' periodicity of $3\phi_0$ and the 'braiding phase' $2\pi/3$ due to quasiparticles that re-enter the interiour of the MZI. As was theoretically predicted, the resultant magnetic field's periodicity corresponded to a single 'flux quantum'. The flux-dependent visibility of the interference oscillations, $\nu_{e/3}$, deviated markedly from that of the electronic one, ν_e. It agreed with approximately $\nu_{e/3} \approx \nu_e^3$, and peaked sharply at an MZI transmission away from that of the Integer-MZI (at half-transmission).

References:

1. Kundu, H.K., et al., Anyonic interference and braiding phase in a Mach-Zehnder interferometer. Nature Physics, 2023. 19, p. 515–521.
2. Law, K.T., D.E. Feldman, and Y. Gefen, Electronic Mach-Zehnder interferometer as a tool to probe fractional statistics. Physical Review B, 2006. 74(4): p. 045319.

Braiding of Anyons at Quantum Point Contacts

Speaker: Heung-Sun Sim (KAIST)

Time: 4:30 pm - 5:05 pm, Jan 3rd.

A quantum point contact (QPC) is useful for identifying quantumness of particles moving along quantum Hall edge channels. In the integer quantum Hall regime, partitioning of a dilute beam at a QPC results in particle antibunching due to the particle discreteness, while collision of two beams exhibits the electronic Hong-Ou-Mandel effects originating from the fermionic exchange statistics. Recently dilute anyon beams were injected to a QPC in the fractional quantum Hall regime at filling factor 1/3, to identify the quantumness of Abelian anyons [1-5].

We predict a new effect [6,7] that dominates over the conventional partition or collision in the regime of the experiments. In the effect, an anyon excited at the QPC braids (in time domain) the anyons of the dilute beams arriving at the QPC within the time window of the excitation. This effect of anyonic braiding statistics has no counterpart in bosons and fermions, vanishing in the integer quantum Hall regime. The resulting current noise agrees with the experimental results by a single dilute beam [2] and two dilute beams [1,3,4], identifying braiding of Abelian anyons in both the cases. This effect is generalized with non-Abelian anyons [7].

References:

1. H. Bartolomei et al, Science 368, 173 (2020).
2. J.-Y. M. Lee et al., Nature 617, 277 (2023).
3. P. Glidic et al., Phys. Rev. X 13, 011030 (2023).
4. M. Ruelle et al., Phys. Rev. X 13, 011031 (2023).
5. B. Rosenow, I. P. Levkivskyi, and B. I. Halperin, Phys. Rev. Lett. 116, 156802 (2016).
6. B. Lee, C. Han, and H.-S. Sim, Phys. Rev. Lett. 123, 016803 (2019).
7. J.-Y. M. Lee and H.-S. Sim, Nat. Comm. 13, 6660 (2022).

Time-domain Braiding of Anyons

Speaker: Gwendal Fève (Institut Universitaire de France)

Time: 5:05 pm - 5:40 pm, Jan 3rd.

Recent experimental evidences of anyon fractional statistics [1-5] have been obtained so far in the DC regime, precluding any investigation of anyon dynamics. I will present how by studying the scattering of single anyon pulses at a quantum point contact, one can probe the dynamics of anyon tunnelling and demonstrate the influence of anyon braiding mechanisms on the characteristic timescales for anyon transfer.

Subnanosecond current pulses carrying a fractional charge can mimic the behaviour of topological anyons, with a fractional statistics that can be continuously tuned by varying the fractional charge carried by each pulse [6-8]. They thus offer the possibility to study, in the time domain, the braiding mechanisms occurring between anyons impinging on a QPC and anyons tunnelling at the QPC, as revealed in recent anyon collider experiments [1,3-5].

By generating anyon pulses on-demand, we characterize the dynamics of anyon tunnelling by implementing a Hong-Ou-Mandel (HOM) experiment between two anyon pulses emitted towards a quantum point contact (QPC) in a fractional quantum Hall fluid at filling factor $\nu = 1/3$. As proposed in [8], the characteristic timescale of anyon tunnelling is directly imprinted in the temporal width of the HOM dip of the current noise at the outputs of the QPC as a function of the time-delay between the arrival of the two anyon pulses. As a consequence of anyon braiding, we observe that the HOM dip is controlled by the scaling dimension δ and increases when decreasing the electronic temperature. This contrasts with the electron case, where braiding is absent, and where the width of the HOM dip is set by the temporal width of the emitted electron current pulses, as naively expected.

This experiment provides a striking illustration of the peculiar properties of anyons, contrasting with fermions and bosons and introduces new tools to study the role of braiding on the dynamics of topological excitations.

References:

1. H. Bartolomei et al., Science 368, 173 (2020).
2. J. Nakamura S. Liang, G. C. Gardner, and M. J. Manfra, Nature Physics 16, 931 (2020).
3. M. Ruelle et al., Phys. Rev. X 13, 011031 (2023).
4. P. Glidic et al., Phys. Rev. X 13, 011030 (2023).
5. J.-Y. M. Lee et al., Nature 617, 277 (2023).
6. J.Y. Lee, C. Han, H.S. Sim, Phys. Rev. Lett. 125, 196802 (2020)
7. C. Mora, arXiv:2212.05123 (2022)
8. T. Jonckheere, J. Rech, B. Grémaud, and T. Martin, Phys. Rev. Lett. 130, 186203 (2023)

Bound States of Composite Fermions

Speaker: Jainendra Jain (Penn State University)

Time: 9:00 am - 9:35 am, Jan 4th.

This talk will report on our recent work on two types of bound states of composite fermions. One is their pairing at even-denominator fractions, including that at half and quarter filled Landau levels in wide quantum wells [1] or in hole type systems [2]. The second concerns STM experiments wherein an external electron tunnels into a complex bound state of an odd number of excited composite fermions dressed by additional composite-fermion excitons; the STM is essentially a spectroscopy of the internal energy levels of this bound state [3]. The results of the theoretical calculations will be compared with experiments.

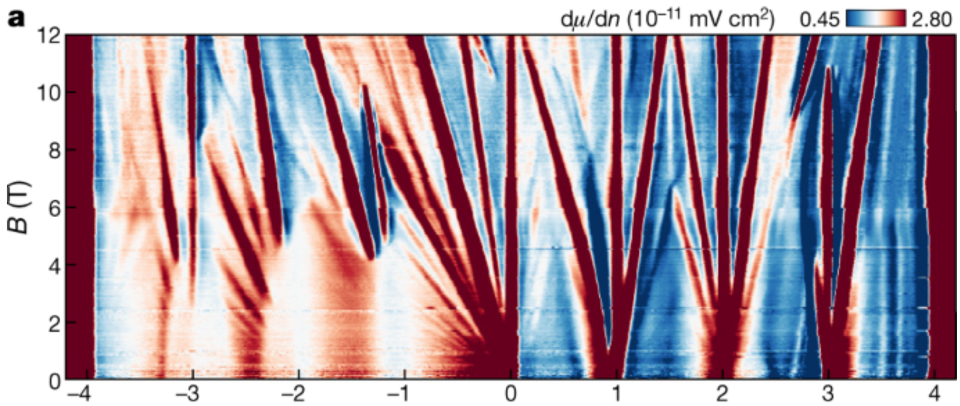
References:

1. A. Sharma, A.C. Balram, and JKJ, arXiv:2311.05083 (2023).
2. T. Zhao, A.C. Balram, JKJ, PRL 130, 186302 (2023).
3. Mytraya Gattu, G. J. Sreejith, JKJ, arXiv:2312.07114 (2023).

Fractional Chern Insulators and Symmetry Breaking in Twisted Graphene

Speaker: Xie Yonglong (Harvard University)

Time: 9:35 am - 10:10 am, Jan 4th.



Fractional Chern insulators in twisted bilayer graphene.

Fractional Chern insulators (FCIs) are lattice analogues of fractional quantum Hall states that may provide a new avenue toward fractionalized and non-abelian excitations even at zero magnetic field. Early theoretical studies have predicted their existence in systems with energetically flat Chern bands and highlighted the critical role of a particular quantum band geometry. Magic angle twisted bilayer graphene (MATBG) supports flat Chern bands at zero magnetic field, and therefore offers a promising route toward stabilizing zero-field FCIs. Here we describe our recent observation of FCI states at low magnetic fields in MATBG enabled by high-resolution local compressibility measurements [1]. Our findings highlight the interplay between symmetry, topology and interactions that leads to a competition between ordered electronic solid phases and fractionalized electronic liquid phases. Our findings strongly suggest that FCIs may be realized at zero magnetic field and pave the way for exploring and manipulating anyonic excitations in moiré systems. I will also discuss our most recent work demonstrating strong correlations and symmetry breaking in a supermoiré lattice [2].

References:

1. Y. Xie et al. Nature 600, 439-443 (2021).
2. Y. Xie et al. In preparation.

Observation of Fractional Quantum Anomalous Hall Effect

Speaker: Xu Xiaodong (University of Washington)

Time: 10:10 am - 10:45 am, Jan 4th.

The interplay between spontaneous symmetry breaking and topology can result in exotic quantum states of matter. A celebrated example is the quantum anomalous Hall (QAH) state, which exhibits an integer quantum Hall effect at zero magnetic field due to topologically nontrivial bands and intrinsic magnetism. In the presence of strong electron-electron interactions, fractional-QAH (FQAH) states at zero magnetic field can emerge, which is a lattice analog of fractional quantum Hall effect without Landau level formation. In this talk, I will present experimental observation of FQAH states in twisted MoTe2 bilayer, using combined magneto-optical and -transport measurements [1-3]. In addition to the Chern number -1 integer, and -2/3 and -3/5 fractional QAH states, we find an anomalous Hall state near the filling factor -1/2, whose behavior resembles that of the composite Fermi liquid in the half-filled lowest Landau level of a two-dimensional electron gas at high magnetic field. Direct observation of the FQAH and associated effects paves the way for researching charge fractionalization and Anyonic statistics at zero magnetic field.

References:

1. Observation of Fractionally Quantized Anomalous Hall Effect, Heonjoon Park et al., Nature (2023), `https://www.nature.com/articles/s41586-023-06536-0`;
2. Signatures of Fractional Quantum Anomalous Hall States in Twisted MoTe2 Bilayer, Jiaqi Cai et al., Nature (2023), `https://www.nature.com/articles/s41586-023-06289-w`;
3. Programming Correlated Magnetic States via Gate Controlled Moiré Geometry, Eric Anderson et

al., Science (2023), https://www.science.org/doi/full/10.1126/science.adg4268.

Identifying non-Abelian quantum Hall states

Speaker: David Mross (Weizmann Institute)

Time: 11:00 am - 11:35 am, Jan 4th.

Non-Abelian phases are among the most highly prized but elusive states of matter. Their exotic quasiparticles are reflected in neutral modes, which are difficult to detect in conventional charge-based measurements. I will propose two routes for identifying the most prominent candidate non-Abelian phases. Firstly, I will describe an experiment to determine the topological order of the $\nu = 5/2$ state by measuring the electric conductance on a specific mesoscopic device. Secondly, I will explain how various non-Abelian topological orders can be identified from noise measurements at their interface to judiciously chosen Abelian states.

Composite Fermions and the Fractional Quantum Anomalous Hall Effect

Speaker: Hart Goldman (Massachusetts Institute of Technology)

Time: 11:35 am - 12:10 pm, Jan 4th.

Recent experiments have revealed evidence for fractional quantum anomalous Hall (FQAH) states at zero magnetic field in a growing number of moire materials. In this talk, I will argue that a composite fermion description, already a unifying framework for the phenomenology of 2d electron gases at high magnetic fields, provides a similarly powerful perspective in this new zero-field context. In particular, a central prediction of the composite fermion framework is a non-Fermi liquid metal of composite fermions at even-denominator fillings. To this end, I will present exact diagonalization evidence for such composite Fermi liquid states at zero magnetic field in twisted $MoTe_2$ bilayers, at fillings $n = 1/2$ and $n = 3/4$. Dubbing these states anomalous composite Fermi liquids (ACFLs), I will argue that they play a central organizing role in the FQAH phase diagram. I will also develop a long wavelength theory for this ACFL state, which offers concrete experimental predictions that I will discuss in relation to current measurements. For example, upon doping the composite Fermi sea, one obtains a Jain sequence of FQAH states consistent with those observed experimentally, as well as a new type of commensurability oscillations originating from the superlattice potential intrinsic to the system. Finally, I will discuss opportunities for new physics not possible in quantum Hall systems at finite magnetic field.

Probing Chiral Graviton Modes in Fractional Quantum Hall Liquids

Speaker: Lingjie Du (Nanjing University)

Time: 12:10 pm - 12:45 pm, Jan 4th.

In the fractional quantum Hall (FQH) state at filling factor $nu = 1/3$, emerging modes dubbed chiral gravitons were proposed as spin-2 quasiparticles from metric fluctuations under the geometry description [1-4], which could also be described by the corresponding Fierz-Pauli equations for gravitons [5-7]. Extended to resembling FQH states, the modes are characterized by polarized states with chirality [8-10] of +2 or 2, and energy gaps coinciding with fundamental lowest-energy neutral excitations (i.e., magnetorotons [11]) in the long-wavelength limit. However, such modes remain experimentally inaccessible. Here, we observe long-wavelength chiral spin-2 magnetorotons in FQH liquids using inelastic scattering of circularly-polarized lights, providing evidence of chiral graviton modes. At $\nu = 1/3$, we identify the long-wavelength magnetoroton as shown in Figure 1. The mode emerges under a specific polarization scheme corresponding to angular momentum -2, which persists at extremely-long wavelength. As contrast, the finite-momentum mode at the energy minimum of magnetoroton does not have such spin selectivity. The chirality of the long-wavelength magnetoroton remains -2 at $\nu = 2/5$ but becomes opposite at $\nu = 2/3$ and 3/5. The spin-2 modes have very sharp peaks with marked temperature and magnetic field dependence, and excellently follow the energy scaling $\Delta \propto E_c/|2p+1|$ $\big(E_c = e^2/\epsilon l_B$ is the Coulomb energy, ϵ is the dielectric constant, $l_B = \sqrt{\hbar c/eB_\perp}$ is the magnetic length), confirming their long-wavelength magnetoroton characteristics. Our observations capture the essentials of the graviton modes and support the FQH geometrical description. We discuss other explanations including the two-roton model, which are hard to explain the experimental results.

References:

1. F. D. M. Haldane, Phys. Rev. Lett. 107, 116801 (2011).
2. B. Yang, Z.-X. Hu, Z. Papić, and F. D. M. Haldane, Phys. Rev. Lett. 108, 256807 (2012).
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5. M. Fierz, and W. Pauli, Proc. R. Soc. London, Ser. A 173, 211 (1939).
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9. D. X. Nguyen, and D. T. Son, Phys. Rev. Res. 3, 023040 (2021).
10. D. X. Nguyen, F. D. M. Haldane, E. H. Rezayi, D. T. Son, and K. Yang, Phys. Rev. Lett. 128, 246402 (2022).
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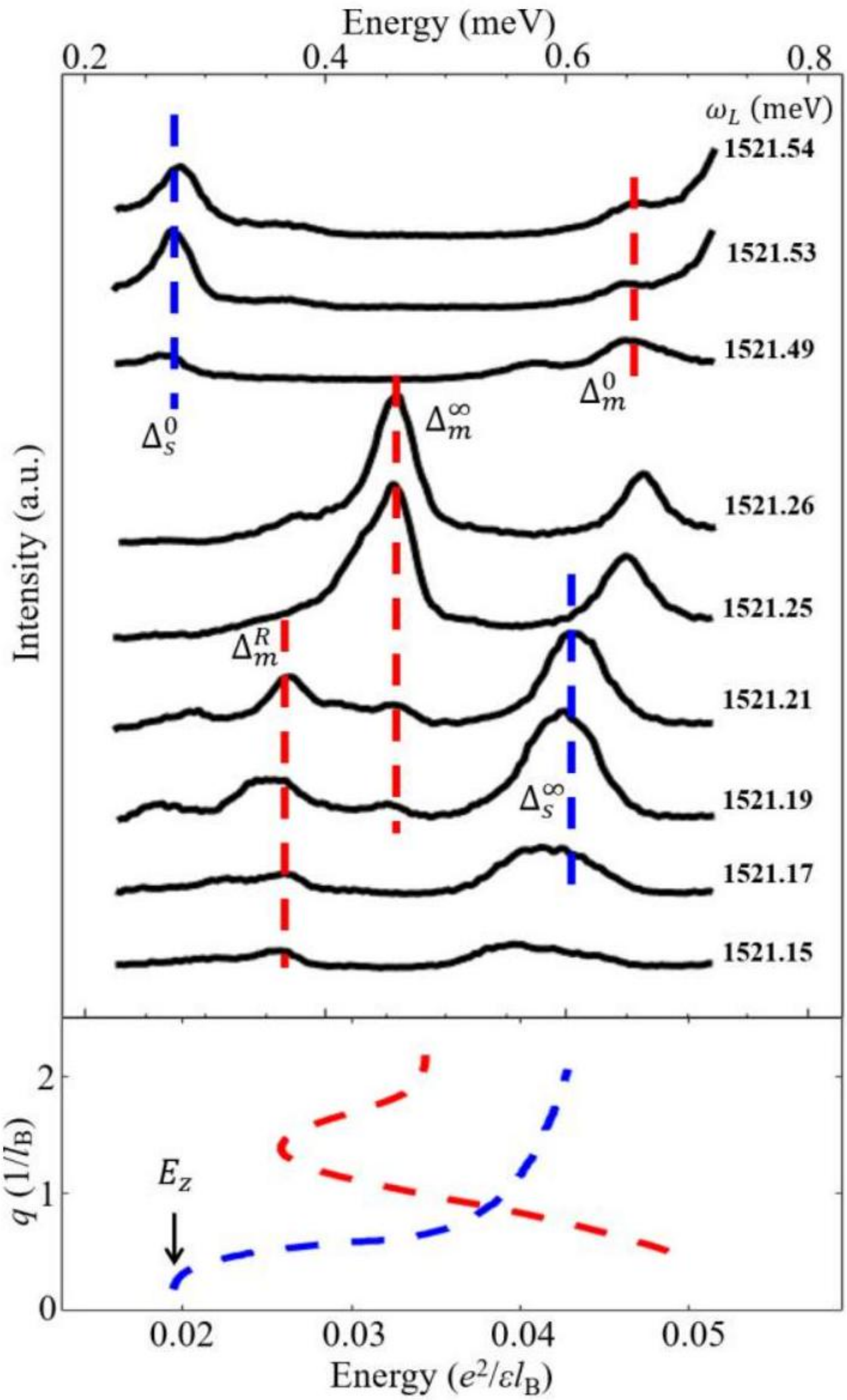


Upper panel present Inelastic light scattering spectra at $v = 1/3$. Red and blue dashed lines indicate magnetoroton and spin-wave excitations of the FQH state, respectively. Lower panel shows calculated dispersions of collective excitations at $v = 1/3$. The red dashed line is scaled down from the ideal zero width 2D result of the magnetoroton [12]. The blue dashed line is a generic dispersion of the spin-wave dispersion.

Updates on the Fractional Quantum Hall Effect in Bilayer Graphene

Speaker: Jun Zhu (Penn State Eberly College of Science)

Time: 1:50 pm - 2:25 pm, Jan 4th.

In a magnetic field, strong electron-electron interaction leads to the celebrated fractional quantum Hall (FQH) effect, in particular even-denominator FQH states, which are predicted to host non-Abelian excitations essential for topological quantum computing. Bernal-stacked bilayer graphene (BLG) introduces new twists to this well-studied phenomenon owing to orbital and valley isospins. In this talk, I'll discuss some of recent progress. Higher order FQH states with the denominators of 13 and 17, as described in Levin and Halperin, PRB 79, 205301 (2009), are observed in the vicinity of the even-denominator FQH states. Their appearance suggests broken particle-hole symmetry at the even-denominator FQH states. We observe daughter states of the anti-Pfaffian 6/13 and 9/17 near filling factor 5/2 and daughter states of the Pfaffian 8/17 and 7/13 near other even-denominator states [1]. BLG also exhibits conventional and unconventional two-component FQH states. As we tune the valley isospin Zeeman splitting, the $|+0\rangle$ and $|-0\rangle$ Jain FQH states undergo a series of valley isospin polarization transitions, well described by the theory of an SU(2) spin. In addition, we observed new FQH states at the coincidence of $|+0\rangle$ and $|-1\rangle$ LLs for a number of fractions, pointing to unconventional two-component states. Finally I will briefly discuss the fabrication and operation of a Fabry-Pérot interferometer in BLG [2].

References:

1. Huang et al., "Valley Isospin Controlled Fractional Quantum Hall States in Bilayer Graphene", Phys. Rev. X. 12, 031019 (2022). Erratum Phys. Rev. X 12, 049901 (2022)
2. Fu et al., "Aharonov–Bohm Oscillations in Bilayer Graphene Quantum Hall Edge State Fabry–Pérot Interferometers", Nano Lett. 23, 718-725 (2023).

Critical Phenomena on a Quantum Fuzzy Sphere: Uncovering Conformal Symmetry in the 3D Ising Transition

Speaker: Wei Zhu (Westlake University)

Time: 2:25 pm - 2:55 pm, Jan 4th.

We introduce a theoretical scheme to study the phase transition and critical phenomena on the space-time geometry $S^{d-1} \times R$, using the "fuzzy (non-commutative) sphere" regularization. As a showcase, we apply this scheme to the quantum version of 3D Ising phase transition. We demonstrate almost prefect state-operator correspondence (i.e. radial quantization), an important property of conformal field theory. The complete conformal data (scaling dimensions, operator product expansion coefficients, etc.) have been explicitly worked out, many of which go beyond the current conformal bootstrap computation. Moreover, our result directly elucidates the emergent conformal symmetry of the 3D Ising transition, a conjecture made by Polyakov half a century ago.

Non-Linear Hall Response Senses Topological Transition in a Moiré Superlattice

Speaker: Mandar Deshmukh (Tata Institute of Fundamental Research)

Time: 2:55 pm -3:30 pm, Jan 4th.

Topological aspects of electron wavefunction play a crucial role in determining the physical properties of materials. Berry curvature and Chern number are used to define the topological structure of electronic bands. While Berry curvature and its effects in materials have been studied detecting changes in the topological invariant, Chern number, is challenging; particularly changes of valley Chern type. In this regard, twisted double bilayer graphene (TDBG) has emerged as a promising platform to gain electrical control over the Berry curvature hotspots and the valley Chern numbers of its flat bands. In addition, strain induced breaking of the three-fold rotation (C_3) symmetry in TDBG, leads to a non-zero first moment of Berry curvature called the Berry curvature dipole (BCD), which can be sensed using nonlinear Hall (NLH) effect. We reveal, using TDBG, that the BCD detects topological transitions in the bands and changes its sign [1]. In TDBG, the perpendicular electric field tunes the valley Chern number and the BCD simultaneously providing us a tunable system to probe the physics of topological transitions.

Reference: Sinha et al. Nature Physics 18, 765 (2022).

Emergent Dynamics of Scale-Free Interactions in Fractional Quantum Hall Fluids

Speaker: Yang Bo (Nanyang Technological University)

Time: 3:30 pm - 4:05 pm, Jan 4th.

Coulomb interaction seems to play a special role not only in experiments but also in theory, for which the composite fermion (CF) theory works particularly well variationally. Model interactions with pseudopotentials, on the other hand, are less suited for CF wavefunctions but are exactly solvable at low energy. We show these two families of interactions can be unified in the language of scale-free interactions. In particular, even with an arbitrarily large cyclotron gap, Landau level (LL) mixing can be dominant with scale-free interactions in a fractional quantum Hall system as long as the filling factor exceeds certain critical values. Such scale-free interaction with kinetic energy can serve as exact model Hamiltonians for certain composite Fermion or parton states (unlike the well-known TK Hamiltonians where the number of

LLs needs to be fixed by hand), and they are natural physical Hamiltonians for 2D systems embedded in higher dimensional space-time.

Even with LL mixing, the null spaces of such Hamiltonians (spanned by the ground state and the quasiholes) can be analytically obtained, and we show these are the generalizations of the conformal Hilbert spaces (CHS) to more than one LL. The effective interaction between the anyons for these topological phases emerges from the kinetic energy of the "elementary particles", leading to an interesting duality between strongly and weakly interacting systems that can be easily understood via the tuning of parameters in the scale-free interaction. We also propose a novel experimental platform for approximately realizing such model Hamiltonians with trion-like particles that can potentially lead to very robust (non-Abelian) FQH phases from two-body Coulomb-based interaction.

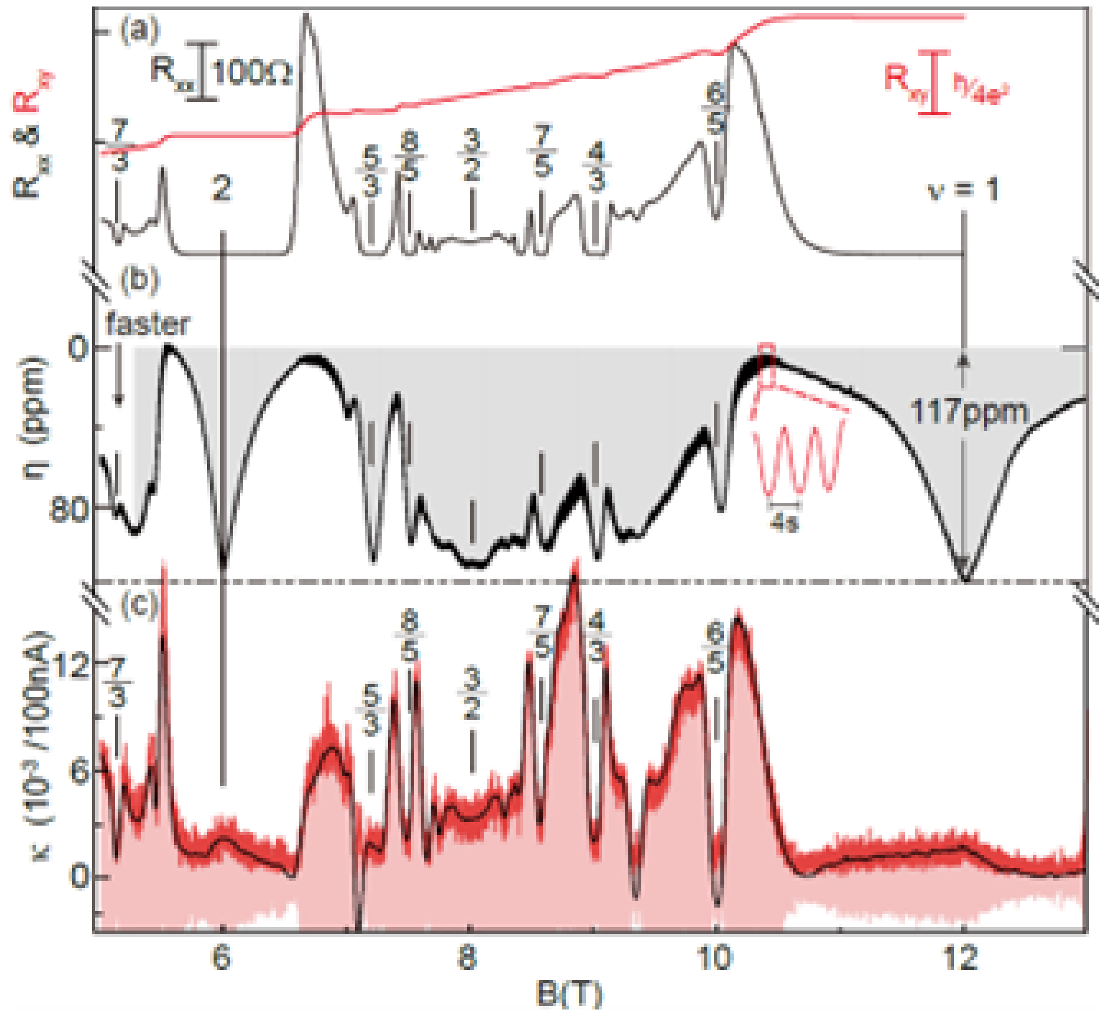
References:

1. Bo Yang, Phys. Rev. B. (Rapid Communication) 100, 241302(R) (2019).
2. Ha Quang Trung and Bo Yang, Phys. Rev. Lett. 127, 046402 (2021).
3. Bo Yang, arXiv:2307.06361.

Morphing of Quantum Phases when Hosting Current

Speaker: Liu Yang (Peking University)

Time: 9:00 am - 9:35 am, Jan 5th.



(a) Longitudinal and Hall resistance measured by quasi-DC lock-in technique. (b) Measured SAW velocity shift. An oscillation is induced by a ~ 500 nA current passing through the sample. (c) The current-induced oscillation and its amplitude, extracted from panel (b) data.

Measurement is an important concept in quantum mechanics, where the reservoir interact with the quantum system through a perturbative field and we capture the property of the quantum system from the stimulated evolution. In this work, we study the ultra-high mobility two dimensional electron systems via its interaction with a propagating surface acoustic wave (SAW) [1,2].

The electron density is 2.9×10^{11} cm^{-2} and low-temperature mobility is about 2×10^7cm^2/(Vs). The 2DEG has a van der Pauw geometry mesa and we evaporate four interdigital transducers at each edge of the mesa. The measurements are carried out in a dilution refrigerator whose base temperature is below 20 mK. By applying an AC voltage whose frequency matches the resonance condition, the IDT generates a propagating SAW which will be captured by the IDT on the opposite side of the sample as a voltage output. The typical input RF power in this study is 1 nW (-61 dBmW), and only a tenth of which turns into SAW considering the attenuation of cables and the efficiency of the IDT.

We directly deduce the SAW velocity shift $\eta \propto \Phi$ from the measured SAW phase shift Φ, and the result is shown in Fig. 1(b). At high magnetic fields, η trace exhibits minimum (enhanced SAW velocity) when the 2DEG forms incompressible quantum Hall liquid. The velocity enhancement becomes more pronounced when the quantum Hall effect is stronger. When a 500 nA AC current passing through the 2DES, we observe an about 4 second period, $\sim$ 1 ppm amplitude oscillation in η, see the expanded inset in Fig. 1(b). We apply a digital band-pass filter to the Fig. 1(b) data and plot the oscillation (pink shade), and/or use a lock-in amplifier to measure the amplitude of this oscillation (black trace).

Our extensive study shows that SAW velocity increases when a current passing through the sample, suggesting that a current-carrying 2DES is more incompressible. Such a current-induced velocity increase illustrates that a close and careful examination on the current flowing mechanism is essential and imperative.

References:

1. A. Wixforth, J. P. Kotthaus, and G. Weimann, Phys Rev Lett. 56, 2104 (1986).
2. Mengmeng Wu, Xiao Liu, Renfei Wang, Yoon Jang Chung, Adbhut Gupta, Kirk W. Baldwin, Loren Pfeiffer, Xi Lin, Yang Liu, arXiv: 2307.02045 (2023).

Identifying Charge-Neutral Excitations in Graphene's Quantum Hall

Speaker: Anindya Das (Indian Institute of Science Bangalore)

Time: 9:35 am - 10:10 am, Jan 5th.

In Quantum Hall (QH) systems, charge-neutral excitations, modes, and quasi-particles exist but are hard to study using traditional electrical conductance measurements due to their charge-neutral nature. This talk will introduce a new, efficient technique called "noise thermometry" to detect these entities in graphene QH.

The first part focuses on detecting charge-neutral upstream modes in "hole-conjugate" fractional QH states of graphene. The magnetic field directs carriers to flow along the downstream edge mode, but these states also have counter-propagating chiral edge modes along both downstream and upstream directions, with the upstream modes predicted to be charge-neutral and carry energy, but not electrical current. Excess noise along the upstream direction was detected as evidence of these ballistic, charge-neutral upstream modes. The second part focuses on detecting magnons in graphene QH ferromagnet (QFM) using noise thermometry. A noiseless DC current flows along the downstream direction when injected at an edge contact, but magnons are generated and propagate in all directions when the bias energy exceeds the Zeeman energy. By placing a "probe floating" contact along the upstream direction, where no electrical current flows, the absorption of magnons leads to finite excess noise above the Zeeman energy and remain linear with the bias. Our "noise thermometry" provides a sensitive tool for detecting charge-neutral excitations in graphene QM.

Thermodynamics of Non-Abelian Fractional Quantum Hall States

Speaker: Michael Zaletel (UC Berkeley)

Time: 10:10 am - 10:45 am, Jan 5th.

Non-abelian anyons are characterized by their topological degeneracy. Cooper and Stern proposed this degeneracy could be detected via the resulting thermodynamic entropy produced by a finite density of non-Abelian anyons. However, observing this effect experimentally requires a careful understanding of non-universal contributions to the entropy coming from the residual motion of the anyons. I will discuss efforts to theoretically model the thermodynamics of a finite density of anyons and make comparison with experiment.

Gate-Tunable Fractional Chern Insulators in Twisted Double Bilayer Graphene

Speaker: Liu Zhao (Zhejiang University)

Time: 11:00 am - 11:35 am, Jan 5th.

Fractional Chern insulators (FCIs) generalize the conventional fractional quantum Hall effect from continuum two-dimensional electron gases to lattice setups. Nowadays a main trend in the development of this field is to realize FCIs in van-der-Waals heterostructures with moiré patterns. In this talk, I propose twisted double bilayer graphene (TDBG) as a versatile platform for the realization of FCIs without the need of a magnetic field. In the chiral limit at the magic twist angle, the TDBG has an exactly flat conduction band carrying Chern number $C = 2$ and ideal quantum geometry, supporting model FCIs as the zero-energy ground states of suitable short-range interactions. When considering realistic parameters of the system beyond the chiral limit, the conduction band of TDBG can carry $C = 1$ and $C = 2$, which is controlled by tuning the vertical gate potential and the twist angle. Remarkably, we find compelling numerical evidence of various FCIs in different regions of band Chern number, including spin-valley polarized states and spin singlet Halperin states. We try to understand the stability of these states by considering the energetics and quantum geometry of the topological flat band.

Exploring the Emergent Phenomenon and Material Systems of Three-Dimensional Quantum Hall Effect

Speaker: Liyuan Zhang (Southern University of Science and Technology)

Time: 11:35 am - 12:10 pm, Jan 5th.

In 2019, our research team achieved a breakthrough by experimentally validating the three-dimensional quantum Hall effect and its associated phenomena in $ZrTe_5$ and $HfTe_5$ bulk crystals. This investigation has revealed a remarkably intricate realm of physical mechanisms dictating the emergence of the three-dimensional quantum Hall effect, featuring Chern vector behavior, dimensionalities, topology evolution, as well as a spectrum of novel quantum states and phase transitions. Beyond the confines of $ZrTe_5$ and $HfTe_5$ crystals, early experiments have unveiled analogous platform behavior reminiscent of the quantum Hall effect in a diverse array of narrow band gap semiconductor crystals—such as InAs, InSb, $Hg_{1-x}Cd x Te$, HgSe, Bi_2Te_3, Bi_4I_4, among others. This collective body of evidence strongly suggests the potential realization of the three-dimensional quantum Hall effect across a broader spectrum of crystal material systems, thereby expanding its applicability to diverse scientific contexts.

Here I will present our team's latest experimental advancements, concentrating on alternative materials like Bi_2O_2Se, HgSe, and InSb, etc. The presentation will delve into a detailed examination of experimental data, analysis methods, and the intricate aspects involved in device preparation and measurement technology for three-dimensional systems. Additionally, I will shed light on critical considerations for conducting experiments in this domain. This talk not only consolidates our current findings but also provides a forward-looking perspective on subsequent research pertaining to quantum phase transitions and dimensional alterations within three-dimensional electronic systems. The insights shared here aim to contribute to a broader understanding of the intricate interplay between quantum phases and their material systems in three electronic systems.

Some new results on FQH plateau transitions

Speaker: G. J. Sreejith (IISER Pune)

Time: 12:10 pm - 12:45 pm, Jan 5th.

Composite fermion wavefunctions describe a one-to-one correspondence between the low energy properties of the FQH and the IQH phases which has been tested extensively in experiments and through numerical studies. Here we consider the FQH state in the presence of a weak disorder potential. The full many-body problem is numerically difficult [1,2] but the effective Hamiltonian of a single quasiparticle can numerically be calculated in a weak disorder regime; and here we find a one-to-one correspondence between the FQH and the IQH systems [3]. If this correspondence extends to the many quasiparticle cases as well, we expect the FQH transitions to be similar to the IQH plateau transitions. The many-quasiparticle problem in the FQH system is numerically intractable even within the variational space. So we turn to experiments and show results from a recent set of experiments on graphene that show similar critical behaviour at both FQH and IQH transitions [4].

References:

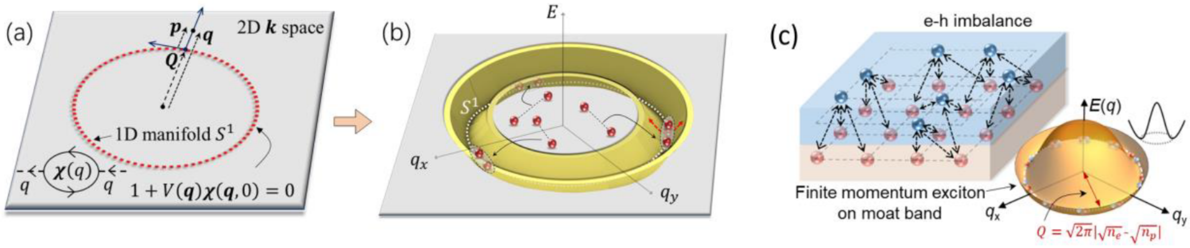
1. Sheng et al. Phys. Rev. Lett. 90, 256802 (2003)
2. Krishna et al. Phys. Rev. B 99, 041111(R) (2019)
3. Pu et al. Phys. Rev. Lett., vol. 128, 116801 (2022)
4. Kaur et al. arXiv:2312.06194

Susceptibility Indicator for Chiral Topological Orders Emergent from Correlated Fermions

Speaker: Wang Rui (Nanjing University)

Time: 1:50 pm - 2:25 pm, Jan 5th.

Chiral topological orders formed in correlated fermion systems have been widely explored. Here, we propose a susceptibility condition and show that, under this condition, chiral topological orders can spontaneously take place in correlated fermion systems. The condition leads to a low energy effective theory of bosons with strong frustration, mimicking the flat band systems. The frustration then melts the long range orders and results in topological orders with time reversal symmetry breaking. We apply the theory to electron hole bilayers with density imbalance. A novel excitonic topological order with semionic excitations and chiral excitonic edge state is theoretically revealed. Experimentally, we observe an unconventional time reversal symmetry breaking excitonic ground state in density-imbalanced InAs/GaSb quantum wells, which exhibits remarkable magneto transport behavior in consistent with the excitonic topological order. These results demonstrate a general mechanism of chiral topological orders as well as



(a) The correlated fermion systems satisfying the susceptibility condition on a momentum loop embedded in the 2D k-space. (b) Under the susceptibility condition, a low energy effective theory takes place, which describes the fermion pairs on a moat-shaped band with the energy minima on the loop c A schematic of an imbalanced bilayer where the electron density is lower than the hole density. An electron could form pairs with different individual holes, leading to a large number of competing configurations with close energies, i.e., the frustration for excitons. Consequently, a moat band would emerge in the dispersion of excitons.

their possible realization in excitonic systems.

References:

1. Rui Wang, Tigran Sedrakyan, Baigeng Wang, Lingjie Du, and Rui-Rui Du, Nature 619, 57.
2. Rui Wang, Tao Yang, Baigeng Wang, and X. C. Xie, arXiv: 2308.09241.

[Special session] Interferometry in Quantum Hall States with Two Coupled Edge Modes

Speaker: Bert Halperin (Harvard University)

Time: 2:25 pm - 3:10 pm, Jan 5th.

Significant experiments have been performed in quantum Hall interferometers where the two-dimensional electron liquid is well shielded by a nearby gate and the system is in a quantized Hall state with two Coulomb-coupled co-propagating edge modes. One example is the recent study of the fractional quantized Hall state at Landau-level filling factor $\nu = 2/5$, carried out by the Purdue group. Another example[1], which I shall describe, is a very recent set of measurements at Harvard on a graphene interferometer in the integer quantum Hall regime, with Landau-level filling factors $\nu \geq 2$. I shall discuss theoretical calculations of effects that are both linear and non-linear in the applied bias voltage. The theory was done in collaboration with Zezhu Wei and D. E. Feldman.

Reference: Thomas Werkmeister, et al.: http://arxiv.org/abs/2312.03150.

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