2024 International Symposium on Quantum Fluids and Solids (QFS24)

Hyatt Regency Jacksonville Riverfront

July 24-30, 2024

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1. General information

Welcome to QFS2024

We are delighted to welcome participants from around the world to the 2024 International Symposium on Quantum Fluids and Solids (QFS24), at the Hyatt Regency Jacksonville Riverfront in Jacksonville, Florida, USA, from July 24-30, 2024!

Emergency contacts

To reach the organizers, please email or call: mailto: qfs2024@magnet.fsu.edu, +1 3522940833. All emergency services (police, fire, ambulance) can be contacted by calling 911.

Wireless network

Complimentary standard Wi-Fi internet access is available in all guestrooms and public areas for the duration of the conference.

Conference Venue

All conference activities will take place on the third floor at the Hyatt Regency Jacksonville Riverfront, using CONFERENCE CENTER A as the main conference room. The conference room floor map can be accessed via this link: https://assets.hyatt.com/content/dam/hyatt/hyattdam/documents/2020/01/22/1054/Hyatt-Regency-Jacksonville-Floor-Plan-English.pdf

Registration

Delegates will collect badges at registration which will be open 16:00-19:00 on Wednesday and 8:00-18:30 on Thursday. Please wear your badge at all times, this is a security requirement and will enable you to identify fellow delegates.

Oral presentations

For your PPT presentation, please plan to bring your PPT in a 16:9 format (4:3 will also display correctly) on a USB flash drive that will need to be uploaded to the main session room laptop before the start of your session.

Posters

Posters should be put up not later than the morning coffee break and removed before 19:00.

Conference banquet

The Conference Banquet will take place on the third floor at the Hyatt Regency Jacksonville Riverfront on Monday 29th of July.

Eating arrangements

Coffee and snacks will be available at the conference venue in the morning (10:00) and afternoon (15:00). Lunch buffets will be provided at the venue, for the four full days of talks, between 12:00 and 13:30. For dinners, participants will be on their own to explore Jacksonville 's wide range of restaurants. Download the Dinner & Drinks in Downtown Jacksonville PDF here: https://pwd.aa.ufl.edu/qfs/wp-content/uploads/sites/34/2023/12/Dinner-Drinks-Downtown-Jax.pdf

Travel Information

To and from airport: Jacksonville International Airport is 15 miles, about a 20-minute drive, from the Hyatt Regency. This is the best airport to book flights to and from. It is recommended that you book a ride-share, taxi, or rental car depending on your needs. The hotel does not offer an airport shuttle.

Parking: The hotel offers both valet and self-parking options, with a discounted $15 a day self-parking rate.

2. Program overview

Wednesday 24 July
16:00-19:00 REGISTRATION &WELCOME RECEIPTION

Thursday 25 July
8:30 Welcome Speech
9:00-10:00 SESSION TH1 **He3-1**
10:00-10:30 COFFEE
10:30-12:00 SESSION TH2 **BECs-Vortices-1**
12:00-13:30 LUNCH
13:30-15:00 SESSION TH3 **QFC-1**
15:00-15:30 COFFEE
15:30-17:00 SESSION TH4 **VQT-1**
17:00-19:00 POSTER SESSION 1

Friday 26 July
8:30-10:00 SESSION FR1 **QIS**
10:00-10:30 COFFEE
10:30-12:00 SESSION FR2 **CS**
12:00-13:30 LUNCH
13:30-15:00 SESSION FR3 **QFS Devices**
15:00-15:30 COFFEE
15:30-17:30 POSTER SESSION 2 (Sponsor: Maybell Quantum) **17:30-18:45 QC LECTURE 1**

Saturday 27 July
8:30-10:00 SESSION SA1 **TSM**
10:00-10:30 COFFEE
10:30-12:00 SESSION SA2 **He3-2**
12:00-13:30 LUNCH
13:30-15:00 SESSION SA3 **QLS-1**
15:00-15:30 COFFEE
15:30-17:30 POSTER SESSION 3 (Sponsor: Oxford Instruments) **17:30-18:45 QC LECTURE 2**

Monday 29 July
8:30-10:00 SESSION MO1 **IEQ**
10:00-10:30 COFFEE
10:30-12:00 SESSION MO2 **QLS-2**
12:00-13:30 LUNCH
13:30-15:00 SESSION MO3 **VQT-2**
15:00-15:30 COFFEE
15:30-16:30 SESSION MO4 **BECs-Vortices-2**
16:45-17:00 QFS26 Intro and Poster Award
18:00-20:00 Conference Banquet

Tuesday 30 July
8:30-10:00 SESSION TU1 **QFC-2**
10:00-10:30 COFFEE
10:30-12:00 SESSION TU2 **CT**

3. Program

Thursday 25 July		
8:30-9:00 Welcome and Introduction		
8:30		Yoonseok Lee, Welcome Speech
8:40		Mark Meisel (Maglab), The MagLab High B/T Facility at the University of Florida - Overview and Invitation to Potential Users
8:50		Theodore Hodapp (Moore), Introduction on the Betty and Gordon Moore Foundation
9:00-10:00 SESSION TH1 **He3-1** *Chair*: Yoonseok Lee		
9:00	TH1.1	Yutaka Sasaki, Detecting Chiral Vector Orientation of Chiral Domains in Superfluid ^{3}He-A
9:20	TH1.2	Samuli Autti, Two-dimensional boundary superfluid at the edges of bulk superfluid ^{3}He
9:40	TH1.3	Alexander Shook, Pumping Suppressed Gap States in ^{3}He-A via Fourth Sound Resonance
10:00-10:30 COFFEE		
10:30-12:00 SESSION TH2 **BECs-Vortices-1** *Chair*: Makoto Tsubota		
10:30	TH2.1	Vincent Liu, Chiral Atomic superfluidity in Orbital Optical Lattice
10:50	TH2.2	Yong-il Shin, Universal Kibble-Zurek Scaling in an Atomic Fermi Superfluid
11:10	TH2.3	Jae-yoon Choi, Universality class of a spinor Bose-Einstein condensate far from equilibrium
11:30	TH2.4	Alberto Villois, Vortex to Rotons Transition in Dipolar Bose-Einstein Condensates
11:45	TH2.5	Wei-can Yang, Vortex efimov effect
12:00-13:30 LUNCH		
13:30-15:00 SESSION TH3 **QFC-1** *Chair*: Vladimir Eltsov		
13:30	TH3.1	Silke Weinfurtner, Rotating Curved Spacetime Signatures from a Giant Quantum Vortex
13:50	TH3.2	John Davis, HeLIOS: Searching for Wavelike Dark Matter Using Superfluid Electromechanics
14:10	TH3.3	Rena Zieve, Rotational Glitches in Superfluid Helium
14:30	TH3.4	Patrik Svancara, Dynamical Processes in a Quantum Liquid-Based Gravity Simulator
14:45	TH3.5	Ken Obara, Superfluid Suction Vortex Generated by Fountain-pump
15:00-15:30 COFFEE		
15:30-17:00 SESSION TH4 **VQT-1** *Chair*: Wei Guo		
15:30	TH4.1	Yosuke Minowa, Excitation and Three-Dimensional Observation of Kelvin Waves on Quantized Vortices
15:50	TH4.2	Mathieu Gibert, Direct visualization of the quantum vortex lattice structure, oscillations, and destabilization in rotating ^{4}He
16:10	TH4.3	Andrei Golov, Visualization of the interaction of micron-sized particles with vortices in superfluid ^{4}He down to 140 mK
16:30	TH4.4	D. E. Zmeev, Investigating Steady and Oscillatory Flows in Helium Using a Superconducting Levitation System
17:00-19:00 POSTER SESSION 1		

17:00-19:00 POSTER SESSION 1 TH5 **QFC + VQT**

TH5.1	Faezeh Ahangarfirouzjaei, Morphology of rotating superfluid drops
TH5.2	M. Arrayas, Evolution of vortex filaments in the Gross-Pitaevski equation and approximation by the binormal flow equation
TH5.3	Kenta Asakawa, Non-circular orbital rotation of two parallel quantized vortices and resonance with collective mode in self-gravitating Bose-Einstein condensate
TH5.4	Jiří Blaha, Starting vortices shed by an airfoil accelerating in superfluid helium
TH5.5	Issei Doki, Rotaing quantum turbulence in a Bose-Einstein condensates: Competetion between isotropization by turbulence and anisotropization by rotation
TH5.6	Chris Goodwin, Visualizing quantum turbulence in superfluid helium-4 in the $T \rightarrow 0$ limit
TH5.7	D. Zmeev, Quantum turbulence detected by a Pillbox-type torsional oscillator
TH5.8	Mikai F. Hulse, Experimental study of boundary layer flows in superfluid helium-4
TH5.9	Sosuke Inui, Turbulent diffusion and dispersion in ultra-quantum and quasiclassical superfluid turbulence
TH5.10	Ashlea Kemp, Photon detection near absolute zero for the QUEST-DMC experiment.
TH5.11	Adam Mayer, Study of the A-B phase transition of ^{3}He in a magnetically confined bubble
TH5.12	Ken Obara, Asymmetrical growth of Quantum Turbulence at both sides of Counterflow- tube
TH5.13	Charles Peretti, Visualising quantized vortex lines in a He II counterflow under rotation
TH5.14	Yinghe Qi, Particle Levitation Velocimetry for boundary layer measurements in high Reynolds number liquid helium turbulence
TH5.15	Tineke Salmon, QUEST-DMC: Constructing a sub-cm^{3} superfluid bolometer for a dark matter search
TH5.16	Lidia Saluto, Coupling of heat flux and vortex polarization in superfluid helium
TH5.17	David Schmoranzer, Nanomechanical oscillators as detectors of quantum turbulence in superfluid helium
TH5.18	Yoshihiro Yabuuchi, Quantum turbulence generated by normal-fluid turbulence in co-flow of superfluid ^{4}He
TH5.19	Zikang Wang, A channel geometry of an ion pool for the study of vortex nucleation in superfluid He
TH5.20	Yiming Xing, Exploring Kibble-Zurek mechanism in superfluid helium-4 using ultrasound
TH5.21	Hikaru Ueki, Searching for Axions and Nonlinear QED with Superconducting RF Cavities

Friday 26 July		
8:30-10:00 SESSION FR1 **QIS** *Chair*: Denis Konstantinov		
8:30	FR1.1	Dafei Jin, Recent progress in electron-on-solid-neon qubits
8:50	FR1.2	Gerwin Koolstra, Progress in readout and control of an electron qubit floating on helium
9:10	FR1.3	Asher Jennings, Plasmon-photon coupling using electrons on helium
9:30	FR1.4	Kaiwen Zheng, Hybrid circuit QED platform between a transmon and an electron-on-solid-neon charge qubit
9:45	FR1.5	Toshiaki Kanai, Single-electron qubits based on quantum ring states on solid neon surface
10:00-10:30 COFFEE		
10:30-12:00 SESSION FR2 **CS** *Chair*: James Sauls		
10:30	FR2.1	John Saunders, Cooling, noise mitigation, and decoherence in quantum circuits immersed in a quantum fluid bath
10:50	FR2.2	Pertti J. Hakonen, Evidence for Bose-Einstein condensation of vacancies in helium adsorbed on a carbon nanotube
11:10	FR2.3	Igor Boettcher, Superfluid phase transition of nanoscale-confined helium-3
11:30	FR2.4	Adrian Del Maestro, Friedel Oscillations in One-Dimensional Superfluid ^{4}He
11:45	FR2.5	Keiya Shirahama, Superfluidity of ^{4}He films adsorbed on hexagonal boron nitride
12:00-13:30 LUNCH		
13:30-15:00 SESSION FR3 **QFS Devices** *Chair*: Dafei Jin		
13:30	FR3.1	Yogesh Patil, A proposal for detecting the spin of a single electron in superfluid helium
13:50	FR3.2	Xavier Rojas, Observation of Duffing Non-Linearity in a Superfluid Sonic Crystal
14:10	FR3.3	Maciej Zgirski, Quasiparticle Creation and Annihilation using a Single Manipulable Superconducting Vortex
14:30	FR3.4	Hyoungsoon Choi, All-metallic gate-tunable superconducting microwave resonators
14:45	FR3.5	Nicholas R. Poniatowski, Detecting induced unconventional superconductivity with cQED
15:00-15:30 COFFEE		
15:30-17:30 POSTER SESSION 2 (Sponsor: Maybell Quantum)		
17:30-18:45 QC LECTURE 1		
Stephen A. Lyon, Quantum Computing: Where Have We Come? Where Are We Going?		

15:30-17:30 POSTER SESSION 2 FR4 QIS + CS + BEC V + CT

FR4.1	Yousef Alihosseini, Accelerator cavity quench spot detection using particle tracking velocimetry
FR4.2	C. C. E. Elmy, On the development of a 2-D LC detection system for flying balls in superfluid helium
FR4.3	Rasul Gazizulin, Cooling a 1D quantum wire using a liquid ^{3}He immersion cell
FR4.4	Chao Huan, Probing Quantum Phenomena using Bay 2 of the High B/T Facility
FR4.5	Shumpei Iwasaki, Pairing and excitation structure of an odd-frequency superfluid Fermi gas
FR4.6	Yongmin Kang, New experimental platform for two-dimensional helium film adsorbed on a graphene substrate
FR4.7	Akihiro Kanjo, Methods to verify inertia of a quantum vortex in superfluid atomic gases
FR4.8	Juiyin Lin, Comparison of RF reflectometry and image charge detection for quantum state detection of electron on helium
FR4.9	S. Murakawa, NMR Measurements of helium three on graphite plated with bilayer of HD
FR4.10	Kostyantyn Nasyedkin, Charge density domain formation in microwave-excited two-dimensional electron system on liquid helium
FR4.11	Yusuke Okajima, Strong-coupling properties of a spin-orbit coupled ultracold Fermi gas and effects of rashbon bound states
FR4.12	Qutadah Rababah, Vacuum Break in a Helium Cooled Tube with an Inserted Cavity
FR4.13	Harini Radhakrishnan, The two body density matrix of a Luttinger liquid
FR4.14	Lalit Kumar Saini, An ab-initio investigation of transition metal-doped graphene quantum dots for the adsorption of hazardous CO_2, H_2S, HCN, and CNCl molecules
FR4.15	A.J. Schleusner, High-frequency dynamics of the liquid and solid phases of electrons on helium
FR4.16	Sergei Sheludiakov, Toward atomically flat solid neon films for scalable electron-on-neon quantum bits
FR4.17	Nicolas Silva, Design and simulation of a copper flake demagnetization cell
FR4.18	Marek Talir, Superfluid optomechanics with lumped element LC cavities
FR4.19	B. Tanatar, Density-wave instability and collective modes in a bilayer of soft-core fermions
FR4.20	B. Tanatar, Density Functional Theory of Rydberg-Dressed Bosonic Atoms in a Harmonic Trap
FR4.21	J. Taniguchi, Potential flow of "superfluid" ^{4}He through a nanoometer-sized channel
FR4.22	J. Taniguchi, Relaxation of the highly mobile state of ^{4}He films due to superfluidity
FR4.23	Cameron Wetzel, A Novel device for formation and investigation of impurity helium condensates containing stabilized atomic species
FR4.24	Akira Yamaguchi, Sample preparation protocol for surface X-ray diffraction of sub-monolayer helium adsorbed on single-surface graphite
FR4.25	Mingyang Zheng, Tunable rectified coulomb drag between quantum wires

Saturday 27 July

8:30-10:00 SESSION SA1 **TSM** *Chair*: John Davis

8:30	SA1.1	Rongying Jin, Quantum-limit phenomena in rare-earth-based layered $EuZn_2As_2$ and $CsNdSe_2$
8:50	SA1.2	Juhn-Jong Lin, Observation of spin-triplet superconductivity in nonmagnetic $CoSi_2/TiSi_2$ heterojunctions
9:10	SA1.3	Long Ju, Fractional Quantum Anomalous Hall Effect in Graphene
9:30	SA1.4	Venkat Chandrasekhar, Searching for signatures of non-trivial topology in diffusive multiterminal Josephson junctions
9:45	SA1.5	James Sauls, Anomalous Hall Effects in Chiral Superconductors

10:00-10:30 COFFEE

10:30-12:00 SESSION SA2 **He3-2** *Chair*: Jeevak Parpia

10:30	SA2.1	Petri Heikkinen, The A-B phase transition of superfluid helium-3 in a stepped-height nanofluidic platform
10:50	SA2.2	John Scott, Orientational transitions in Helium-3 imbibed in anisotropic aerogel
11:10	SA2.3	Riku Rantanen, Vortex core transitions in ^{3}He-B: Answer to a 40-year-old puzzle
11:30	SA2.4	Anton B. Vorontsov, Superfluid He-3 in periodic aerogel structures
11:45	SA2.5	Takeshi Mizushima, Paramagnetic response of superfluid 3He-B in anisotropic aerogel: Anomalous proximity effect and Andreev bound states

12:00-13:30 LUNCH

13:30-15:00 SESSION SA3 **QLS-1** *Chair*: Robert Hallock

13:30	SA3.1	Keith Schwab, Quantum Circuits and Sensors with He-4: Superfluid Analogs of SQUIDs, FOGs, and Ring Lasers Gyroscopes
13:50	SA3.2	Jere Mäkinen, Exploring Fermi superfluids with strongly pinned vortices: Consequences for dynamics and thermodynamics
14:10	SA3.3	Man Nguyen, Transverse Sound in the Quantum Fluid States of He-3
14:30	SA3.4	Atsuki Kumashita, New Heat-capacity Measurements on the Commensurate–Incommensurate Quantum Phase Transition in Submonolayer ^{3}He on ZYX Graphite
14:45	SA3.5	Simon Midlik, Parylene-bonded micro-fluidic channels for cryogenic experiments at superfluid He-4 temperatures

15:00-15:30 COFFEE

15:30-17:30 POSTER SESSION 3 (Sponsor: Oxford Instruments)

17:30-18:45 QC LECTURE 2

Alan Ho, Quantum Supremacy 5 years later

15:30-17:30 POSTER SESSION 3 SA4 IEQ + TSM + ^{3}He + QLS

SA4.1	Andrei Golov, Modelling flow of superfluid ^{4}He past a rough solid wall in the T = 0 limit
SA4.2	Chao Huan, Ultralow-temperature susceptibility and phase diagram of $TmVO_4$ proximate to quantum critical point
SA4.3	Y. Ikegai, Pair annihilation and textural transition of d-soliton lattice in ^{3}He-A
SA4.4	Vladimir Khmelenko, Broad central line observed in esr experiments on hydrogen atom isotopes in solid molecular films of hydrogen isotopes
SA4.5	Ryundon Kim, Tunable superconducting microwave resonator with liquid helium
SA4.6	Oleksandr Korostyshevskyi, Enhanced luminescence of oxygen atoms in solid molecular nitrogen nanoclusters
SA4.7	Sangyun Lee, Pressure induced surface p-wave superconductivity and higher-order topology in $MoTe_2$
SA4.8	Daksh Malhotra, Investigating sub-coherence length confinement in superfluid ^{3}He using nanofluidic Helmholtz Resonators
SA4.9	Valery Milner, Ultrafast dynamics and control of rotons in superfluid helium
SA4.10	Aymar Muhikira, Experimental setup for study of surface states in ^{3}He
SA4.11	S.Murakawa, Angular dependence of Andreev reflection at the surface of superfluid helium-three B phase
SA4.12	Ryuji Nomura, Novel oscillation modes of pendant droplets of superfluid ^{4}He
SA4.13	Prabin Parajuli, Novel experimental platform to realized one-dimensional quantum fluids
SA4.14	Daehan Park, Transverse sound in the Fermi liquid of ^{3}He in a 5μm microfabricated cavity
SA4.15	Priya Sharma, Scattering-Induced Fluidic Hall Effect in Chiral ^{3}He-A
SA4.16	Rahul Soni, Topological and magnetic properties of the interacting Bernevig-Hughes-Zhang model
SA4.17	Yasumasa Tsutsumi, Andreev reflection rate on boundary of superfluid ^{3}He-B
SA4.18	Hikaru Ueki, Topological Hall effects in magnetic metals with chiral spin textures
SA4.19	Yuxin Wang, Failed superconductivity in chemically-substituted Mott spin liquid materials
SA4.20	Cameron Wetzel, Structure of Molecular Nitrogen Nanoclusters Containing Stabilized Nitrogen Atoms
SA4.21	Luke Whitehead, Simulating quasiparticle exchange with a 2D boundary superfluid
SA4.22	Satoshi Yui, Numerical study on Kelvin waves excited by a vibrating nanobeam in superfluid helium-4
SA4.23	Satoshi Yui, Polarized filaments and decay of quantum turbulence coupled with normal-fluid turbulence in superfluid helium-4

Monday 29 July		
8:30-10:00 SESSION MO1 **IEQ** *Chair*: Stephen Lyon		
8:30	MO1.1	Ambarish Ghosh, Signature of electronic phase transitions in multielectron bubbles
8:50	MO1.2	Valery Milner, Rotational Control of Helium Dimers in Superfluid Helium
9:10	MO1.3	Dominique Laroche, Signatures of exciton condensation in Si/SiGe bilayers
9:30	MO1.4	Denis Konstantinov, Rydberg-state detection in a small ensemble of trapped electrons
9:45	MO1.5	Camille A. Mikolas, Plasmon mode engineering and cQED with electrons on helium
10:00-10:30 COFFEE		
10:30-12:00 SESSION MO2 **QLS-2** *Chair*: Eunseong Kim		
10:30	MO2.1	Andrey Vilesov, Phase separation in cold para-H_2 - D_2 clusters
10:50	MO2.2	Ryuji Nomura, Quantum Dripping of Superfluid ^{4}He
11:10	MO2.3	Taku Matsushita, Exploring Tomonaga-Luttinger liquid of the 1D ^{3}He using NMR
11:30	MO2.4	Paul Sokol, Experimental realization of one dimensional helium
11:45	MO2.5	Michele Sciacca, The one-fluid extended model of superfluid helium II: recent results
12:00-13:30 LUNCH		
13:30-15:00 SESSION MO3 **VQT-2** *Chair*: Richard Haley		
13:30	MO3.1	Vladimir Eltsov, Vortex dynamics at sub-quantum length scales, probed with a NEMS device
13:50	MO3.2	Makoto Tsubota, Numerical Studies of Quantum Turbulence
14:10	MO3.3	Emil Varga, Transition from 2D to 3D quantum turbulence
14:30	MO3.4	Amy Lester, Energy Emission from a Trapped Quantum Vortex in Superfluid Helium
14:45	MO3.5	Yusuke Masaki, Second Harmonic Generation by Dynamics of Pinned Vortex
15:00-15:30 COFFEE		
15:30-16:30 SESSION MO4 **BECs-Vortices-2** *Chair*: Yong-il Shin		
15:30	MO4.1	Nir Navon, Atomic Fermi Fluids in Optical Boxes
15:50	MO4.2	Vanderlei Bagnato, Observation of relaxation stages in out-of-equilibrium closed quantum systems: the case of turbulence in atomic trapped superfluid
16:10	MO4.3	Richard Fletcher, Quantum Hall physics in the quantum Foucault pendulum
16:30	MO4.4	Noble Gluscevich, Dynamics of Topological Defects in ^{3}He-A Films following a Quench
16:45-17:00 QFS26 Intro and Poster Award		
18:00-20:00 Conference Banquet		

Tuesday 30 July		
8:30-10:00 SESSION TU1 **QFC-2** *Chair*: William Halperin		
8:30	TU1.1	Scott Hertel, Recent Quantum Evaporation R&D towards the HeRALD Dark Matter Experiment
8:50	TU1.2	Yining You, Superfluid Effective Field Theory: aspects of light dark matter detection and normal fluid viscosity
9:10	TU1.3	Christina Gao, Axion Wind Detection with the Homogeneous Precession Domain of Superfluid Helium Three
9:30	TU1.4	Theo Noble, QUEST-DMC: Looking for Low Mass Dark Matter in Superfluid ^{3}He-B
9:45	TU1.5	Sanjay Shukla, Gravity- and temperature-driven phase transitions in a model for collapsed axionic condensates
10:00-10:30 COFFEE		
10:30-12:00 SESSION TU2 **CT** *Chair*: Christian Enss		
10:30	TU2.1	Rakin Baten, Progress on LCMN thermometery
10:50	TU2.2	Ekaterina Mukhanova, Entanglement and noise in traveling wave Josephson parametric amplifiers
11:10	TU2.3	Andrew Casey, Immersing samples in helium-3, revisiting boundary resistance
11:30	TU2.4	Azimjon Temurjonov, Thermal Relaxation Effect in the Nanopore Heat Exchanger for Dilution Refrigerator
11:45	TU2.5	Natalia Morais, Quasioptical Microwave Field Enhancement for Electron-on-Helium Qubits

4. Abstract

4.1 Oral Presentations: Thursday 25th July

The MagLab High B/T Facility at the University of Florida - Overview and Invitation to Potential Users*

Chao Huan, Rasul Gazizulin, Sangyun Lee, Nicolas Silva, Christopher J. Ollmann, and Mark W. Meisel

Department of Physics and MagLab, University of Florida, Gainesville, FL 32611-8440, USA

The MagLab High B/T Facility (HBT) offers users a safe and welcoming atmosphere for performing research in high magnetic fields and at ultralow temperatures with an ultra-quiet electromagnetic interference environment. The Microkelvin Laboratory on the UF campus was built as a result of an NSF grant, DMR-8419267, awarded to E. Dwight Adams, Gary G. Ihas, and Neil S. Sullivan to realize two ultralow temperature cryostats (Bay 1 and Bay 2) [1]. Since UF funds were used to construct the building, Vice-President for Research Don R. Price authorized a third bay for future expansion, and after the National High Magnetic Field Laboratory was awarded to the FSU-UF-LANL team in 1990, the first MagLab HBT instrument (Bay 3) was built [2]. Using specialized cooling techniques [3], a record minimum electron temperature of 4 mK in a sizeable magnetic field of 4 Tesla was realized [4]. The Bay 2 instrument became a MagLab HBT asset in 2006. In 2019, the Bay 1 space was approved for a new, nimble, dry system, and a Bluefors station (7 mK, 14 Tesla) opened for user science in January 2024.

[1] J. Xu *et al.*, J. Low Temp. Phys. **89** (1992) 719, `https://doi.org/10.1007/BF00694125`
[2] N. S. Sullivan *et al.*, Physica B **294-295** (2001) 519, `https://doi.org/10.1016/S0921-4526(00)00713-4`
[3] J. S. Xia *et al.*, Physica B **280** (2000) 491, `https://doi.org/10.1016/S0921-4526(99)01843-8`
[4] W. Pan *et al.*, Phys. Rev. Lett. **83**, 3530 (1999), `https://doi.org/10.1103/PhysRevLett.83.3530`

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TH1.1 Detecting Chiral Vector Orientation of Chiral Domains in Superfluid ^{3}He-A

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In a thin slab of superfluid ^{3}He-A under an in-plane magnetic field, uniform texture of parallel or anti-parallel $\hat{d}$ and $\hat{\ell}$ directing to a surface normal of the slab is expected to appear. However, experimentally observed MRI images of the textures in a single vertical slab of superfluid ^{3}He-A indicated the existence of several textural domains with thin domain walls in between. The NMR/MRI signatures of the domain walls provide the means to classify them into three kinds of candidates, namely $\hat{\ell}$-wall with reversed $\hat{\ell}$ directions on both sides of the wall, $\hat{d}$-wall with reversed $\hat{d}$, and $\hat{\ell}\hat{d}$-wall with simultaneously reversed $\hat{\ell}$ and $\hat{d}$. Here we report on the $\hat{\ell}$-wall, which stays between two chiral domains. The domain walls has straight plane shape after adequate annealing procedure at temperatures near T_C. They show parallel and vertical alignment with smallest surface area in the case of cooling without external flow. However, in the case of cooling with horizontal super-flow along the slab, the adjacent walls tilt towards different directions with the same tilting angle from vertical direction, hence form a staggered arrangement. We understand that the tilting effect is caused by the orbital super-current term of $\nabla \times \hat{\ell}$ and v_s in bending energy. By arranging the super-flow direction and strength during the annealing procedure, we could manipulate the tilting angles and directions of the chiral domain walls. Thus we observed the evidence of the orbital super-current along chiral domain walls. The chiral vector direction of each chiral domain in slab-shaped chiral superfluid ^{3}He is detected as well.

TH1.2 Two-dimensional boundary superfluid at the edges of bulk superfluid ^{3}He

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The B phase of superfluid ^{3}He at the lowest temperatures is composed of a well-understood bulk bounded by a quantum well, populated by topological edge-state quasiparticles. Here we argue that the edge states form an independent two-dimensional superfluid, which is weakly coupled to the bulk and facilitates heat transport across macroscopic distances. The independence is demonstrated by careful analysis of experiments where the bound states are emitted from the surface to the bulk, to be replenished by diffusive flow along the surface [1,2]. Experiments also provide evidence for this long-distance transport. The edge states interact with bulk quasiparticles that scatter from the boundary. We describe experiments where two bulk volumes are separated by a constriction, designed to suppress the bulk quasiparticle transport. This allows us to make the dynamics of the edge states experimentally accessible. Our work shows that these states are essential for facilitating basic physical processes such as the thermalisation of quasiparticles in the bulk superfluid. These findings transform our understanding of this versatile quantum condensate and open the possibility of engineering two-dimensional quantum condensates of arbitrary topology.

1. S. Autti *et al*, Nature Communications **14**, 6819 (2023)
2. S. Autti *et al*, Nature Communications **11**, 4742 (2020)

TH1.3 Pumping Suppressed Gap States in ^{3}He-A via Fourth Sound Resonance

A. J. Shook, E. Varga, I. Boettcher, and J. P. Davis

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The superfluid phase of ^{3}He is made possible due to the existence of a gap in the quasi-particle dispersion relation. At a surface, this gap is suppressed leading to Andreev bound state excitations which can exist near the surface but not in the bulk superfluid[1]. The existence of these bound states modifies the Landau criterion for pair-breaking during AC flow via a process where surface-bound states are continuously pumped into the bulk[2]. We have presented evidence that for highly confined slabs (750-1800 nm thickness) of ^{3}He-A a critical velocity appears that is consistent with the onset of this dissipation mechanism[3]. This measurement is made possible using our Helmholtz resonator devices, which can drive fourth sound and achieve stabilization of a static texture due to the high degree of confinement. Further development of our measurement technique may provide a platform for studying the physics of bound state excitations in the A-phase, which would be inaccessible to mechanical oscillators submersed in bulk fluid due to the dynamic texture.

1. A. B. Vorontsov, Phil. Trans. R. Soc. A. 376, 20150144 (2018).

2. C. A. M. Castelijns, K. F. Coates, A. M. Guénault, S. G. Mussett, and G. R. Pickett, Phys. Rev. Lett. 56, 69 (1986).

3. A. J. Shook, E. Varga, I. Boettcher, and J. P. Davis, Phys. Rev. Lett. 132, 156001 (2024).

TH2.1 Chiral Atomic superfluidity in Orbital Optical Lattice

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Orbital is another fascinating degree of freedom complimentary to charge and spin. It is known to play a rudimentary role in understanding the nature of superfluid pairings, such as s-, p-, and d-wave. In condensed matter, through its coupling to spin and charge, orbital order intertwines superconductivity, magnetism, and other quantum phenomena. The advanced spatiotemporal control of optical lattices provides new opportunities to explore orbital physics beyond standard quantum regimes achieving unique aspects. Here, I will present on theoretical and experimental progress on ultracold atoms trapped in the orbital bands of optical lattices in novel geometries [1,2]. A globally chiral atomic superfluid is predicted by theoretical analysis— and observed by experiment in a long-lived Bose-Einstein condensate of ^{87}Rb atoms — in the second Bloch band of an optical lattice with hexagonal boron nitride geometry [3]. This phase of matter spontaneously breaks time-reversal symmetry driven by interaction, analogous to ferromagnetic order in a spin system. Time-of-flight and band mapping measurements reveal that the local phases and orbital rotations of atoms are spontaneously ordered into a vortex array, showing evidence of the emergence of global angular momentum across the entire lattice. A phenomenological effective model is derived to capture the dynamics of Bogoliubov quasi-particle excitations, whose band structure are found topological. This realizes a form of bosonic topological superfluidity, expected to exhibit phenomena that are conceptually distinct from, but related to, the quantum anomalous Hall effect in electronic condensed matter.

1.M. Lewenstein and W. V. Liu, Orbital dance, Nature Physics 7, 101 (FEB 2011)
2.Physics of higher orbital bands in optical lattices: a review, X. Li, W. V. Liu, Rep. Prog. Phys. 79, 116401 (2016)
3. X.-Q. Wang, G.-Q. Luo, J.-Y. Liu, W. V. Liu, A. Hemmerich, and Z.-F. Xu, Evidence for an atomic chiral superfluid with topological excitations, Nature 596, 227 (2021).

TH2.2 Universal Kibble-Zurek Scaling in an Atomic Fermi Superfluid

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In systems undergoing symmetry-breaking phase transitions, spatial domains of the ordered phase can randomly develop, potentially leading to the formation of topological defects at their interfaces. The Kibble-Zurek mechanism (KZM) offers a universal framework for predicting the formation of these defects, establishing a power-law relationship between the number of defects and the rate of the phase transition. In this talk, I will present our experimental observations of Kibble-Zurek scaling in a homogeneous, strongly interacting Fermi gas during a superfluid phase transition.[1,2] We explored this transition using two distinct control parameters: temperature and interaction strength. Although the microscopic dynamics of condensate formation differed significantly between these parameters, evidenced by a two orders of magnitude difference in formation timescales, the Kibble-Zurek exponent was consistently observed around 0.68 across both scenarios, aligning well with theoretical predictions for superfluid phase transitions. Additionally, I will discuss phenomena beyond the KZM, including defect saturation in rapid quenches and the early-time coarsening dynamics observed in the developing condensate.[3.4]

1. K. Lee *et al.*, arXiv:2310.05437.
2. B. Ko *et al.*, Nat. Phys. **15**, 1227 (2019).
3. J. Goo *et al.*, Phys. Rev. Lett. **127**, 115701 (2021).
4. J. Goo *et al.*, Phys. Rev. Lett. **128**, 135701 (2022).

TH2.3 Universality class of a spinor Bose-Einstein condensate far from equilibrium

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Understanding and classifying out-of-equilibrium dynamics in a closed quantum many-body system have been outstanding problems in modern physics. In this talk, we will introduce our recent experimental results on the universal coarsening dynamics in spin-1 Bose-Einstein condensate. Initially prepared polar condensate is quenched to ferromagnetic phases by microwave dressing. Right after the quench, we observe the emission of spin 1/-1 pairs due to dynamical instability, forming microdomains, which are coarse to form a larger domain as time evolves. We find distinctive scaling behavior depends on the symmetry of the Hamiltonian and associated dynamics of topological defects like domain walls and spin vortices. In the second part of this talk, I will also introduce our recent experiment on the quantum Kelvin Helmholtz instability (KHI). After preparing a single magnetic domain wall, we impose a counterflow by applying a magnetic field gradient. The flutter-finger pattern, the hallmark of the KHI, is observed on the magnetic domain boundary. In the nonlinear dynamic stage, a magnetic droplet is emitted from the tip of the figure, and further analysis shows that it has a fractional skyrmion charge with breaking axis symmetry.

1. Huh, S. *et. al.*, Nature Physics **20**, 402 (2024). "Universality class of a spinor Bose-Einstein condensate far from equilibrium".

TH2.4 Vortex to Rotons Transition in Dipolar Bose-Einstein Condensates

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Recent experimental advancements enabled the creation of various systems exhibiting superfluid behavior, with one notable achievement being the development of Dipolar Bose-Einstein condensates (dBECs) characterized by long-range dipole-dipole interactions. When confined along one or more spatial dimensions, these condensates exhibit a low-dimensional dispersion relation reminiscent of superfluid liquid helium, featuring a roton minimum[1]. Unlike conventional helium, dBECs allow for direct visualization of small-scale vortex structures. Furthermore, mean-field models based on Gross-Pitaevskii-like equations accurately depict the behavior of ultracold Bose gases, enabling exploration of the interaction between vortical structures and roton excitations. This study investigates the existence of two-dimensional solitary waves characterized by topological defects (quantized vorticity) and their transition to vortex-free Jones-Roberts solitons[2]. The explicit connection between solitary waves and roton excitations is demonstrated for the first time, providing support for Feynman's hypothesis regarding the nature of rotons as fading vortex excitations.

1. D. Petter, G. Natale, R. M. W. van Bijnen, A. Patscheider, M. J. Mark, L. Chomaz, and F. Ferlaino (2019) Phys. Rev. Lett. 122, 183401
2. C. A. Jones and P. H. Roberts (1982) J. Phys. A: Math. Gen. 15 2599

TH2.5 Vortex efimov effect

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The three-body problem, from the chaotic motions of celestial bodies to complex microscopic particle interactions, has always been one of the most foundational yet intricate challenges in physics since its establishment. It embodies simplicity and universality while harboring deep complexities and mysteries. A key breakthrough in this domain is the Efimov effect, which represents a significant stride in what is now known as Efimov physics. Our study uncovers a macroscopic efimov effect in a three-component Bose-Einstein Condensate (BEC) system. Here, within specific parameters, three vortices form a bound state, removing one vortex causes the others to unbind, demonstrating topological characteristics similar to the Borromean rings, hence termed the 'vortex efimov effect'. We propose several experimental approaches to realize this macroscopic efimov effect, paving new paths not only in multibody physics but also in exploring quantum phase transitions and applications in quantum information.

TH3.1 Rotating Curved Spacetime Signatures from a Giant Quantum Vortex

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Gravity simulators are laboratory systems where small excitations like sound or surface waves behave as fields propagating on a curved spacetime geometry. The analogy between gravity and fluids requires vanishing viscosity, a feature naturally realised in superfluids like liquid helium or cold atomic clouds. Such systems have been successful in verifying key predictions of quantum field theory in curved spacetime. In particular, quantum simulations of rotating curved spacetimes indicative of astrophysical black holes require the realisation of an extensive vortex flow in superfluid systems. Here we demonstrate that despite the inherent instability of multiply quantised vortices, a stationary giant quantum vortex can be stabilised in superfluid 4 He. Its compact core carries thousands of circulation quanta, prevailing over current limitations in other physical systems such as magnons, atomic clouds and polaritons. We introduce a minimally invasive way to characterise the vortex flow by exploiting the interaction of micrometre-scale waves on the superfluid interface with the background velocity field. Intricate wave-vortex interactions, including the detection of bound states and distinctive analogue black hole ringdown signatures, have been observed. These results open new avenues to explore quantum-to-classical vortex transitions and utilise superfluid helium as a finite temperature quantum field theory simulator for rotating curved spacetimes.

TH3.2 HeLIOS: Searching for Wavelike Dark Matter Using Superfluid Electromechanics

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Observations spanning multiple astronomical scales point to the existence of an unknown form of matter, dubbed 'dark matter,' which constitutes over 85% of the mass of most galaxies. Recent theoretical insights into the possible nature of dark matter and how it interacts with normal matter have inspired a wide range of experimental efforts aimed at directly detecting dark matter. As a part of this effort, we are developing small scale experiments to search for multiple well-motivated 'ultralight' dark matter candidates [1], placing much stronger bounds than are currently possible with high-cost and/or large-scale efforts. The core enabling technology relies on quantum-limited microwave cavity readout of mechanical motion in superfluid helium. I will tell you about the experiments that have led up to where we are now [2], and our current efforts with regards to this table-top dark matter search [3].

1. J. Manley, D. J. Wilson, R. Stump, D. Grin and S. Singh, Phys. Rev. Lett. 124, 151301 (2020).

2. V. Vadakkumbatt, M. Hirschel, J. Manley, T.J. Clark, S. Singh and J.P. Davis, Phys. Rev. D 104, 082001 (2021).

3. M. Hirschel, V. Vadakkumbatt, N.P. Baker, F.M. Schweizer, J.C. Sankey, S. Singh and J.P. Davis, accepted to Phys. Rev. D (2024). arXiv:2309.07995

TH3.3 Rotational Glitches in Superfluid Helium

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Neutron stars rotate rapidly, often at 100 Hz or more. Their rotation gradually decreases, punctuated by occasional "glitches" where the rotation rate abruptly increases. The glitches are believed to come from depinning and pinning of vortices in the neutron superfluid interior. Here we discuss measurements of similar glitch behavior in superfluid helium. We levitate a container filled with superfluid helium and start it rotating, then allow it to spin freely and monitor its angular velocity as it slows down. We find rotational glitches in the superfluid, in sharp contrast to the smooth slowdown observed when no superfluid is present. We discuss how our experiment helps interpret the neutron star behavior.

TH3.4 Dynamical Processes in a Quantum Liquid-Based Gravity Simulator

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Analogue models of gravity have become useful tools for studying the behaviour of fields in curved spacetimes like rotating black holes. We recently developed such an experimental platform based on a stable giant quantum vortex in superfluid ^{4}He. By driving the vortex flow, we have shown that the corresponding velocity field mimics an effective, rotating curved spacetime if perceived by minute waves propagating on the superfluid interface[1]. Here, we study fundamental dynamical processes relevant to black hole research like ringdown radiation and superradiance, together with their respective signatures in the analogue experiment. We link these phenomena to specific wave modes observed in the experiment by introducing an effective scattering potential that surrounds the giant vortex, showcasing future directions for gravity simulations in superfluids. This research is a part of the Quantum Simulators for Fundamental Physics consortium.

1. Švančara, P. et al. (2024). "Rotating curved spacetime signatures from a giant quantum vortex". Nature **628**, 66-70.

TH3.5 Superfluid Suction Vortex Generated by Fountain-pump

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The core size of the suction vortex is generally determined by the competition between the diffusion of the vorticity due to the viscosity and the transport of the vorticity due to the inward flow. To stabilise the suction vortex of superfluid He, the competition between the repulsive force between the quantized vortex lines and the inward superfluid flow to confine the vorticity plays a key role [1, 2]. Previous studies using a cryogenic turbine have shown that the circulation of the suction vortex is proportional to the turbine speed, but have not been able to quantitatively evaluate the suction flow. Recently, it has been shown experimentally that the fountain effect can be used to generate a superfluid suction vortex[3]. The fountain-pump has no moving parts at low temperatures and the flow through the pump can only be quantitatively controlled by the heater power. We first evaluated the performance of a fountain pump. We then placed the fountain pump at the bottom of a 32 mm diameter glass tube and designed the pump outlet to create a circulating flow at the bottom of the tube. We generated a suction flow of 0.91 cm^2/s at the 2.3 mm diameter suction port and succeeded in creating a suction vortex whose circulation was 18 cm^2/s. Using optical profilometry, the diameter of the core was determined to be 2.2 mm. This result indicates that even in the superfluid, the diameter of the core of the suction vortex is comparable to the diameter of the suction port.

1. Obara, K. (2021). Phys. Rev. Fluids **6**, 064802, "Vortex Line Density of Superfluid Suction Vortex".
2. Kakimoto, N. (2022). J. Low Temp. Phys., **208**, 379 "Circulation of Superfluid Suction Vortex".
3. P. Leiderer, *private communication.*

TH4.1 Excitation and Three-Dimensional Observation of Kelvin Waves on Quantized Vortices

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Kelvin waves, among the most fundamental excitations on vortices, play a crucial role in the energy dissipation process of inviscid superfluids. However, there are limited experimental studies on Kelvin waves in superfluid helium-4 due to the lack of experimental techniques to excite Kelvin waves in a controllable manner. Here, we demonstrate the deliberate excitation of Kelvin waves on quantized vortices in superfluid helium. We also visualized these excited Kelvin waves three-dimensionally to illustrate their helical structure.

1. Y. Minowa, *et al.* arXiv:2402.16411 [cond-mat.quant-gas].

TH4.2 Direct visualization of the quantum vortex lattice structure, oscillations, and destabilization in rotating ^{4}He

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Quantum vortices are a core element of superfluid dynamics and elusively hold the keys to our understanding of energy dissipation in these systems. We show that we can visualize these vortices in the canonical and higher-symmetry case of a stationary rotating superfluid bucket. Using direct visualization, we quantitatively verify Feynman's rule linking the resulting quantum vortex density to the imposed rotational speed. We make the most of this stable configuration by applying an alternative heat flux aligned with the axis of rotation. Moderate amplitudes led to the observation of collective wave mode propagating along the vortices, and high amplitudes led to quantum vortex interactions. When increasing the heat flux, this ensemble of regimes defines a path toward quantum turbulence in rotating ^{4}He and sets a baseline to consolidate the descriptions of all quantum fluids.

1. Peretti, C., Vessaire, J., Durozoy, É., & Gibert, M. (**2023**). "Direct visualization of the quantum vortex lattice structure, oscillations, and destabilization in rotating 4He". **Science Advances**. *https://doi.org/10.1126/sciadv.adh2899*

TH4.3 Visualization of the interaction of micron-sized particles with vortices in superfluid ^{4}He down to 140 mK

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Mechanical Engineering Department, Florida State University, Tallahasse, Florida, USA

We constructed a vibrationally-isolated rotating refrigerator that can cool, down to $T = 0.14$ K, a cell, containing superfluid helium with in-situ dispersed polymer fluorescent particles of diameters in the range 1–6 μm. Particles' positions, within a remotely adjustable illuminating light sheet, were monitored by an intensified camera at the rate up to 990 fps.
The turbulence was generated by a burst of particles injected from the cell's floor by ultrasound. Two types of particle trajectories were observed: erratic random-walk like and nearly straight, suggesting that particles could be either trapped by chaotically moving vortex lines or move untrapped. The erratic trajectories have not been seen below 0.7 K, hinting at the collapse of the lifetime of the trapped state. Velocity PDFs revealed a coexistence of a Gaussian and power-law tails at all temperatures investigated, 0.14 K − 1.4 K. This is similar to the PDFs observed previously at higher temperatures. There, the Gaussian part is due to either the interaction of untrapped particles with the viscous turbulent normal fluid or effect of multiple vortex reconnections on the trajectories of trapped particles; and the power-law tails are likely due to the singular interactions of particles with vortex lines. Yet, as there is no viscosity in superfluid helium at $T \sim 0.14$ K, the Gaussian PDFs of untrapped particles should be coming from a different mechanism – perhaps from the fluctuations of the flow acceleration within the vortex tangle.

TH4.4 Investigating Steady and Oscillatory Flows in Helium Using a Superconducting Levitation System

M. Arrayás, C. C. E. Elmy, D. Field, A. Gheorghe, R. P. Haley, Š. Midlik, E. Mobbs-Pursell, R. Schanen, D. E. Smart, S. Soulerin, J. L. Trueba, C. Uriarte, V. V. Zavjalov, and D. E. Zmeev

Flows produced by steadily moving probes have been largely unexplored in superfluid helium due to the inherent technical challenges. The focus has traditionally been on oscillatory flows.

We report the initial results of a versatile, superconducting levitation system, engineered to examine both steady and oscillatory flows in superfluid helium. We levitated and manipulated indium and lead superconducting spheres using a system of coils within superfluid helium, generating a range of motion profiles. These include uniform linear motion, free oscillations, and sustained, near-uniform circular motion down to 1.5 K. We have also performed measurements in helium gas at 1 bar.

The system's adaptability will stimulate research into numerous areas of interest. These include the cross-over between oscillatory and steady flows, the lift experienced by an aerofoil in a superfluid, and the properties of the edge superfluid in topological ^{3}He-B. We anticipate that this system will enable the study of superfluids in a remanent vortex-free state, achievable by gradually immersing the levitating ball into the superfluid from the vapour phase via the free surface.

4.2 Poster Presentations: Thursday 25th July

TH5.1 Morphology of rotating superfluid drops

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The morphology of rotating classical fluid droplets has been extensively studied, yet spinning superfluid droplets have not yet been thoroughly investigated. We present an experimental setup that enables the observation of a magnetically levitated superfluid helium-4 (He II) droplet and propose a unique technique to impart specific angular momentum to the droplet. This technique utilizes a time-dependent non-axially symmetric magnetic field produced by quadrupole coils aligned facing the center of the levitation region. We also discuss the connection between the droplet morphology and the angular momentum of the rotating droplet[1], showing that the shape of a rotating superfluid droplet can be affected by the presence of quantized vortices within the droplet. This work lays the foundation for our planned investigation on rotating He II droplets and their morphology.

1. Seidel, G. M., Maris, H. J. (1994). "Morphology of superfluid drops with angular momentum. Physica B: Condensed Matter", 194, 577-578.

TH5.2 Evolution of vortex filaments in the Gross-Pitaevski equation and approximation by the binormal flow equation

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The evolution of a vortex line following the binormal flow equation (i.e. with a velocity proportional to the local curvature in the direction of the binormal vector) has been postulated as an approximation for the evolution of vortex filaments in both the Euler system for inviscid incompressible fluids and the Gross-Pitaevski equation in superfluids. We address the issue of whether this is a suitable approximation or not and its degree of validity by using rigorous mathematical methods and direct numerical simulations. More specifically, we show that, as the vortex core thickness ϵ goes to zero, the vortex core moves (at leading order and for long periods of time) with a velocity $\mathbf{v} = |\log\epsilon|\kappa\mathbf{b}$, where κ is the local curvature and $\mathbf{b}$ the binormal vector to the curve. The main idea of our analysis lies in a reformulation of the Gross-Pitaevski equation in terms of associated velocity and vorticity fields that resemble the Euler system written in terms of vorticity in its weak form. We also present full numerical simulations aimed to compare Gross-Pitaevski and binormal flow in various physical situations of interest such as the periodic evolution of deformed vortex rings and the reconnection of vortex filaments.

TH5.3 Non-circular orbital rotation of two parallel quantized vortices and resonance with collective mode in self-gravitating Bose-Einstein condensate

K. Asakawa and M. Tsubota

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We report the results of orbital rotation of two parallel quantized vortices in a self-gravitating Bose-Einstein condensate (BEC). This BEC is bound for its own gravitational potential which is determined by its density profile. This property is different from that of usual atomic BECs trapped by external potentials. While the BEC has been investigated in some works[1], the dynamics of quantized vortices in the BEC remain non-trivial. We study the motion of two parallel quantized vortices in the BEC to understand that. The two quantized vortices rotate around the center of the BEC at a constant angular velocity while deforming their vortex cores and exciting the collective modes. Their trajectories differ depending on their initial positions. When the vortices are close to the center of the BEC, they exhibit elliptical orbits; otherwise, they spiral out. This suggests that effective dissipation for the vortices works when their initial positions are beyond a certain critical distance from the center of the BEC. This dissipation mechanism, dependent on the initial positions of the vortices, is likely generated by the resonance between the oscillation/rotation of the vortices due to core deformation and the quadrupole mode of the BEC. Such non-trivial behaviors of quantized vortices reflect the influence of attractive long-range interaction.

1. L. Hui, Annu. Rev. Astron. Astrophys., **59**, 247 (2021); K. Asakawa, *et al.*, arXiv:2307.14018 (2023):PTEP (in press); T. Matos, *et al.*, Front. Astron. Space Sci. **11**, 1347518 (2024).

TH5.4 Starting vortices shed by an airfoil accelerating in superfluid helium

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We study experimentally the starting vortices shed by a relatively large airfoil, accelerating uniformly from rest in superfluid helium-4, at various values of temperature and acceleration. The flow-induced motions of small solid particles, illuminated by a laser sheet, are captured by a digital camera. From the particle positions and velocities, the trajectory and relative strength of the shed vortices are estimated by using the Lagrangian pseudovorticity[1]. The experimental results are then compared with a self-similar scaling theory[2], derived for an inviscid fluid. We find that the starting vortex trajectories do not depend appreciably on the liquid temperature, while their strength is influenced significantly by the imposed acceleration value. Additionally, the visualized vortices move considerably faster than predicted by the theory and, apart from a relatively short initial period, they do not appear to follow the scaling laws obtained analytically. Overall, the outcome can be attributed to viscosity, i.e. the study supports, once more, the idea that large-scale turbulent flows of superfluid helium-4 can be similar to analogous flows of Newtonian fluids, especially when thermal effects can be neglected. We thank P. Dabnichki and M. Rotter for valuable help; we acknowledge financial support from the Ministry of Education, Youth and Sports of the Czech Republic under grant no. LL2326.

1. Outrata, O., Pavelka, M., Hron, J., La Mantia, M., Polanco, J. I. and Krstulovic, G. (2021) "On the determination of vortex ring vorticity using Lagrangian particles" Journal of Fluid Mechanics 924, A44

2. Pullin, D. I. and Wang, Z. J. (2004) "Unsteady forces on an accelerating plate and application to hovering insect flight" Journal of Fluid Mechanics 509, 1

TH5.5 Rotaing Quantum Turbulence in a Bose-Einstein Condensates : Competetion between Isotropization by Turbulence and Anisotropization by Rotation

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Turbulence restores symmetry and induces isotropy in a fluid[1], while rotation induces anisotropy along the rotation axis[2]. The competition of these two effects is interesting[3]. Rotating turbulence in Bose-Einstein condensates(BECs) is investigated by solving the three-dimensional Gross-Pitaevskii equation[4,5]. In this study, we numerically make a lattice of quantized vortices in a rotating BEC trapped by harmonic potential and disturb the BEC with a time-dependent random potential to generate turbulence. This setup is the same as in the previous study[5]; however, we investigate turbulence by changing the amplitude of the random potential and the angular frequency. We analyzed the energy spectra and the particle flux. The anisotropic energy spectra were observed due to the vortex lattice[5]. However, increasing the amplitude of the random potential disturbed the vortex lattice, reduced the number of vortices, and consequently made the turbulence more isotropic. When there are no vortices below the critical angular frequency, turbulence is almost isotropic with little differences in energy spectra and fluxes even if the angular frequency is changed.

1. U. Frisch, Turbulence (Cambridge University Press, Cambridge, 1995).
2. P. A. Davidson, J, Fluid Mech. 557, 135 (2006).
3. M. Tsubota, T. Araki and C. F. Barenghi, Phys. Rev. Lett. 90, 205301 (2003)
4. J. A. Estrada, M. E. Brachet and P. D. Miminni, Phys. Rev. A 105, 063321 (2022)
5. Y. Sano and M. Tsubota, Phys. Rev. A. 109. L031301 (2024).

TH5.6 Visualizing Quantum Turbulence in Superfluid ^{4}He in the $T \to 0$ Limit

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We present the results of an experiment measuring the interactions of micron-scale tracer particles with quantized vortices in superfluid ^{4}He at temperatures down to 140 mK. Our method involves the impulsive injection of particles into the volume of an experimental cell using an ultrasound transducer. The cell is thermally anchored to the mixing chamber of a dilution refrigerator and filled with superfluid helium. Two classes of microspheres, composed of fluorescent dyed polymers, with varying size and density were released into the cell and filmed as they descended through the fluid under the influence of gravity. Using particle tracking velocimetry, the trajectories of the particles were recorded during their descent. The observed particle velocity distributions displayed Gaussian statistics, along with power law tails at all temperatures down to 140 mK. This resembles a combination of classical, viscous interactions with the normal component and non-classical interactions with quantized vortex lines, observed previously at temperatures above 1.4 K. In the case of the low temperature limit, the Gaussian velocity distribution likely originates from the quasi-viscous dynamics of particles within the vortex tangle. The time evolution and temperature dependencies of these distributions have been documented. An analytical technique was developed, using the shape of particle trajectories, to distinguish the motion of particles bound to vortex lines from those which are unbound. The lowest temperature at which particles could be confidently identified as being temporarily bound to vortex lines is 0.7 K.

TH5.7 Quantum Turbulence Detected by a Pillbox-type Torsional Oscillator

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A torsional oscillator in the form of a hollow flat cylinder ("pillbox")[1] connected to a beryllium-copper torsion rod has been successfully used to generate and detect quantum turbulence in superfluid helium at mK temperatures. We report the experimental observations and estimate the mean vortex line density in the cell using the dissipation rate of mechanical energy together with the decay term in the well-known Vinen equation describing the dominant decay mechanism – annihilation of oppositely oriented vortex segments. The estimated mean vortex line density scales with the peak velocity as $L \propto U^{3/2}$, in agreement with earlier work on channel co-flow[2], and also falls within the same order of magnitude. Finally, we present a comparison of turbulence generated in two cells of identical dimensions with rough vs. smooth walls.

1. A. M. Guénault; P. V. E. McClintock et al., A low-frequency, high-amplitude, torsional oscillator for studies of quantum fluids and solids, Physics of Fluids **35**, 045146 (2023).
2. E. Varga, S. Babuin, L. Skrbek, Second-sound studies of coflow and counterflow of superfluid 4He in channels, Physics of Fluids **27**, 065101 (2015).

TH5.8 Experimental study of boundary layer flows in superfluid helium-4

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For classical turbulent flows near a solid wall, it has been well-established that the near-wall mean velocity takes a universal logarithmic profile within the boundary layer, known as the "law of the wall". However, it remains unclear whether this law extends to superfluid helium-4 (He II) boundary-layer flows. This uncertainty arises because He II consists of two fully miscible fluid components: an inviscid superfluid and a viscous normal fluid. The normal fluid adheres to the classical no-slip boundary condition at the wall, whereas the superfluid does not. Any velocity mismatch between the two fluids could induce mutual friction between them, potentially altering the classical law of the wall. Here, we discuss our recent experiments in which we used our molecular tagging velocimetry technique to measure the near-wall velocity profile in a He II pipe flow facility, where pipe-flow Reynolds numbers exceeding 10^6 were achieved. Our results reveal that the log-law near-wall mean velocity profile persists in He II, albeit with a different Kármán constant from that in classical fluids. We also discuss our ongoing efforts to implement superconducting coils in the same flow facility to levitate superconducting bluff bodies for drag measurements in He II.

TH5.9 Turbulent diffusion and dispersion in ultra-quantum and quasiclassical superfluid turbulence

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Turbulent diffusion and dispersion are pivotal in classical turbulence research, yet their exploration in quantum fluids has been comparatively neglected. Here we present a systematic numerical study to fill this gap, focusing on the diffusion and dispersion of vortex segments and superfluid parcels within both ultra-quantum and quasiclassical superfluid turbulence. While recent flow visualization experiments and numerical simulations have indicated that random vortex tangles in ultra-quantum superfluid turbulence may demonstrate generic superdiffusion at short times[1,2], a similar investigation in quasiclassical superfluid turbulence has been lacking. Furthermore, the dynamics of how two vortex segments or two superfluid parcels disperse in these turbulent environments remain poorly understood. Our current study provides a detailed examination of these phenomena, revealing both the similarities and differences in turbulent diffusion and dispersion across these two types of superfluid turbulence. This research not only enhances our understanding of quantum fluids but also contributes to the broader field of fluid dynamics.

1. Y. Tang, S. Bao, andd W. Guo (2021). “Superdiffusion of quantized vortices uncovering scaling laws in quantum turbulence”, Proc. Natl. Acad. Sci. 118, e2021957118.
2. S. Yui, Y. Tang, W. Guo, H. Kobayashi, and M. Tsubota (2022). “Universal anomalous diffusion of quantized vortices in ultra-quantum turbulence”, Phys. Rev. Lett., 129, 025301.

TH5.10 Photon detection near absolute zero for the QUEST-DMC experiment.

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The goal of the QUEST-DMC experiment is to probe well-motivated theoretical models that naturally predict dark matter candidates in the sub-GeV mass range [1]. This will be achieved with a superfluid He-3 target operated at sub-300 microKelvin temperatures. When a particle, such as dark matter, interacts in the superfluid He-3, it will primarily produce quasiparticle excitations that are detected via nanomechanical wire resonators. The small superfluid energy gap for quasiparticle excitations, 1E-7 eV, makes the system an extremely sensitive bolometer. However, for particle interactions with recoil energies above the ionisation energy of He, 20 eV, scintillation photons can also be produced in the superfluid He-3 target. The ability to detect these photons is of high value for QUEST-DMC, whether they are used as a “veto” to reject background interactions such as cosmic rays, or whether they can be used as an additional background discrimination parameter such as through Pulse Shape Discrimination (PSD). The technological challenge lies in designing a photon detector capable of operating at ultra low temperatures. Here I will cover why photon detection is important for QUEST-DMC and the different candidate technologies for such a detector, and will present the results from the most recent experimental data from testing such technologies at 10 mK.

1. Autti, S., et al. “QUEST-DMC superfluid ^{3}He detector for sub-GeV dark matter.” The European Physical Journal C 84.3 (2024): 1-17.

TH5.11 Study of the A-B phase transition of 3He in a magnetically confined bubble

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The study of first-order phase transitions in superfluid Helium-3 can provide valuable insight into the evolution of the early universe [1]. While this phase transition is not expected to occur within the lifetime of the universe, several experiments have directly and repeatedly observed the transition [2]. It is therefore critical to understand the external sources which may cause this nucleation including radiation and interactions with surfaces.

As part of the QUEST-DMC collaboration, we have built a high-field-gradient magnet to create a region where we can supercool or superheat the A and B phases of superfluid of ^{3}He with full control of the size of this bubble. Operating at a range of pressures, we are able to fully isolate the bubble from the cell walls such that it only interacts with the surrounding ^{3}He. By measuring the transport of quasiparticles between two vibrating wire resonators on either side of the bubble, we can study its extent and detect when the phase transition occurs. Finally, we can study how the lifetime of the supercritical phases compares with parameters such as pressure, temperature and size. I will present on the design, construction and initial test results for this experiment.

1. Hindmarsh, M. et al. (2024). "AB transition in superfluid 3He and cosmological phase transitions". J. Low Temp. Phys.
2. Heikkinen, P.J. et al. (2024). "Nanofluidic platform for studying the first-order phase transitions in superfluid helium-3". J. Low Temp. Phys.

TH5.12 Asymmetrical growth of Quantum Turbulence at both sides of Counterflow-tube

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Suppose two chamber, A and B, are connected by a tube and superfluid helium is confined in them; it is known that if heat is injected into chamber A, the normal-fluid component flows from chamber A to B and the superfluid component flows in the opposite direction. This is called thermal counterflow, whose velocity can be controlled by the heater power. It is also known that quantum turbulence can be generated by the thermal counterflow[1], and its transition is believed to be a phenomenon with two critical velocities[2]. We have studied the onset and the asymmetrical growth of the quantum turbulence in these two bulk chamber triggered by the counterflow in the connecting tube.

The experiments were performed at 1.5 and 2.0 K and the onset of the quantum turbulence were determined by the second sound attenuation. The results showed that the heater power required for the turbulence transition were always lower in chamber B than in chamber A. This asymmetrical behavior can be understand on the basis of the vortex theorem; the vortex lines should be driven in the v_s direction, so the quantum turbulence observed in chamber B should not have originated in the tube, they should have been generated by the complex flow occurring in chamber B. On the other hand, no turbulence was observed in chamber A at weak heater power, which was because the vortex lines generated in the tube diffused as soon as they entered chamber A. At high heater power, turbulence was directly generated in chamber A by the counterflow from heater to the tube.

1. Vinen, W.F.,(1956) Proc. of Roy. Soc. A **240**.
2. Martin, K.P., (1983), Phys. Rev. B **27**, 2788.

TH5.13 Visualising quantized vortex lines in a He II counterflow under rotation

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Quantum vortices are a core element of superfluid dynamics and elusively hold the keys to our understanding of energy dissipation in these systems. We use dihydrogen and dideuterieum particles to visualise the vortices in the CryoLEM, an optical rotating cryostat equipped with a counterflow channel. We make use of the reproducible initial condition that is the vortex array formed under rotation of superfluid ^{4}He [1] to study rotating quantum turbulence. Initial observations suggest the existence of three regimes depending on counterflow velocity: unperturbed, oscillations along the vortex lines of the array and turbulence. In the first two regimes, particles decorate the vortex array and enable us to track the vortex dynamics. In the third regime, turbulent flow agglomerates the particles into bigger ones, disabling their ability to track vortices in a clear and sure manner. We aim to provide a clear view of the axial counterflow under rotation experiment and the rich set of quantum turbulence features it exhibits, and directly observe the physics described by Swanson [2] in a similar experiment.

1. Peretti, C., Vessaire, J., Durozoy, É., & Gibert, M. (**2023**). "Direct visualization of the quantum vortex lattice structure, oscillations, and destabilization in rotating 4He". **Science Advances**. *https://doi.org/10.1126/sciadv.adh2899*

2. Swanson C., Barenghi C. and Donnelly R. (**1983**). "Rotation of a tangle of quantized vortex lines in He II". **Physical Review Letters**, Volume 50, 3.

TH5.14 Particle Levitation Velocimetry for boundary layer measurements in high Reynolds number liquid helium turbulence

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Understanding boundary layer flows in high Reynolds number (Re) turbulence is crucial for enhancing aerodynamic performance and operational efficiency across sectors, from commercial aviation to industrial fluid dynamics. However, generating these flows demands complex, power-intensive large facilities, and the use of local probes such as hot wires often introduces disturbances due to necessary support structures, compromising measurement accuracy. Here, we discuss a compact setup that utilizes the vanishingly small viscosity of liquid helium to produce high Re flows and adopts an innovative Particle Levitation Velocimetry (PLV) measurement system. This PLV system employs magnetically levitated superconducting micro-particles to assess boundary layer flows. We demonstrate that a four coaxial coil setup can levitate superconducting micro-particles of various sizes in our Liquid Helium Flow Visualization Facility (LHLVF)[1], serving as flow probes with minimal disturbances. The displacement of these levitated micro-particles can be used to determine the flow velocities and their fluctuations. Our simulations show that this PLV system should enable non-intrusive measurements of the boundary layer over a wall unit range of $22 \leq y^+ \leq 4400$ with a spatial resolution down to 10 μm, thereby opening new avenues for exploring turbulence structures and correlations in the thin boundary layer that would be challenging to achieve otherwise.

1. H. Sanavandi et.al. Rev Sci Instrum 91 (5), 053901 (2020).

TH5.15 QUEST-DMC: Constructing a sub-cm^3 superfluid bolometer for a dark matter search

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On behalf of the QUEST-DMC Collaboration

The QUEST-DMC project, QUantum Enhanced Superfluid Technologies for Dark Matter and Cosmology, is conducting a low mass sub-GeV direct dark matter search using superfluid ^{3}He-B as the target. The detector is a superfluid bolometer comprising of a sub-cm^3 copper box filled and surrounded by ^{3}He-B, containing a vibrating wire resonator thermometer and heater. It is cooled using a custom nuclear demagnetisation refrigerator. The design and construction of the copper bolometer will be discussed, including sensitivity considerations such as materials choices and characteristics of the vibrating wire probes. Calibration runs and proof-of-concept searches have been carried out at pressures between 0 and 29 bar and superfluid temperatures around 0.15 T_c. A summary of these results will be presented. Using a transformer readout we have achieved an energy threshold of 3.5 keV and hope to improve on this with the upcoming run utilising SQUIDs and working at lower temperatures around 0.13 T_c.

1. QUEST-DMC collaboration, QUEST-DMC superfluid He detector for sub-GeV dark matter, Eur. Phys. J. C **84**, 248 (2024).
2. QUEST-DMC collaboration, QUEST-DMC: Background Modelling and Resulting Heat Deposit for a Superfluid Helium-3 Bolometer, J. Low Temp. Phys. accepted, (2024).

TH5.16 Coupling of heat flux and vortex polarization in superfluid helium

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In this poster we present a macroscopic description of the mutual influence between heat flux and vortex polarization in superfluid helium, in which the vortices produce a lateral deviation of the heat flux, and the heat flux produces a lateral drift of vortices.

This coupling is a consequence of a microscopic Magnus force and mutual friction force between the vortices and the flow of excitations carrying the heat. We keep track of these effects with simplified macroscopic equations, and we apply them to second sound propagation between rotating concentric cylinders and to spatial distribution of polarization across a rectangular channel with vortices polarized orthogonally to the channel in the presence of an imposed heat flux.

1. Saluto, L. and Jou, D. (2020). "Coupling of heat flux and vortex polarization in superfluid helium". J. Math. Phys. 61, 113101 (2020); https://doi.org/10.1063/5.0010433.

TH5.17 Nanomechanical Oscillators as Detectors of Quantum Turbulence in Superfluid Helium

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We report on experimental observations of quantum turbulence detected using micro-/nano-mechnical devices submerged in superfluid helium with externally generated flow. The devices respond to turbulent flow by changes in their resonant frequency and/or amplitude. They show sufficient sensitivity for practical use as local probes in both co-flow (driven by a commercial tuning fork) and in thermal counterflow experiments. For the case of a microwire placed in thermal counterflow, a model describing its response to quantum turbulence is proposed[1], based on the boundary layer being modified due to the presence of quantized vortices. Our model compares well with experimental data, where the density of quantized vortices is inferred from second sound attenuation.

1. Midlik, Š., Goleňa, M., Talíř, M. et al., Vibrating Microwire Resonators Used as Local Probes of Quantum Turbulence in Superfluid He, J. Low Temp. Phys. **212**, 168 (2023).

TH5.18 Quantum Turbulence Generated by Normal-Fluid Wall Turbulence in Co-flow of Superfluid ^{4}He

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While the universal logarithmic law of the wall is crucial in the study of classical turbulence, there are still not enough studies on quantum turbulence. Recently, Guo's group[1] observed the logarithmic law of the normal component in co-flowing superfluid ^{4}He, where the mean velocities of the superfluid and normal fluid are in the same direction. Interestingly, the K*á*rm*á*n constant κ obtained by the experiment is different from the universal value $\kappa = 0.41$ of classical turbulence. To identify the cause of the change, we consider the effect of the mutual friction in a vortex tangle state under the co-flow. We performed simulations of the vortex filament model[2] between two parallel plates. Our mean velocity profile of the normal fluid consists of the viscous sublayer, the logarithmic region, and the bulk region. To introduce the turbulence of the normal component, we added an ABC flow[3] to the mean velocity profile. It is found that the turbulence in the normal component is required to create and maintain the vortex tangle under co-flow, unlike the counterflow. Our simulation shows that polarized vortex filaments are collected near the wall. This is a unique feature of the co-flow turbulence. We will discuss how the spatial distribution of mutual friction may affect the change in the K*á*rm*á*n constant.
1. W.Guo, private communications
2. K.W.Schwarz(1988). "Three-dimensional vortex dynamics in superfluid ^{4}He: Homogeneous superfluid turbulence". Phys.Rev.B, Vol 38, 2398
3. T.Dombre, et.al. (1986). "Chaotic stream lines in the ABC flows". J.Flud.Mech, Vol 167, 353

TH5.19 A Channel Geometry of An Ion Pool for the Study of Vortex Nucleation in Superfluid ^{4}He

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Superfluidity in liquid ^{4}He is characterized by the absence of viscosity, and the critical velocity marks the transition from a non-dissipative to a dissipative flow state. In the previous work[1], the critical velocity was observed for a pool of positive ions trapped below a free surface, which was attributed to the nucleation of a quantized vortex associated with the macroscopic quantum tunneling. To study the problem further, here we consider a novel ion pool design where a channel is connected to reservoirs at both ends and examine the response of the system in both linear and nonlinear regimes (i.e., below and above the critical velocity, respectively) using finite element method (FEM) simulations. We find that the velocity in the channel is uniform within 5%, and that the response of the system is well described by the lumped constant circuit model in both linear and nonlinear regimes. These features allow well-controlled investigations of the transport properties of the ions even above the critical velocity, which enables us to quantitatively understand the vortex nucleation process and the vortex state above the critical velocity.

1. D. Takahashi, H. Ikegami, and K. Kono, *J. Low Temp. Phys.* **212**, 214-231 (2023).

TH5.20 Exploring Kibble-Zurek Mechanism in Superfluid Helium-4 Using Ultrasound

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Kibble proposed that symmetry-breaking phase transitions after the Big Bang could lead to the formation of topological defects such as cosmic strings in the early Universe.[1] Zurek extended this idea to condensed matter systems and predicted that quantized vortices would be created in superfluid helium-4 (He II) through the same mechanism following a rapid pressure quench through the lambda line.[2] However, past experiments using bellows-driven expansion cells to observe vortex formation in He II have been inconclusive, possibly generating a small number of vortices that were beyond the detection capabilities of the experimental setups.[3] Here, we discuss a novel experimental approach aimed at overcoming the limitations of previous efforts. This new method employs focused ultrasonic waves to achieve pressure quenches in He II with a controlled quenching time down to the microsecond level, potentially increasing the resulting vortex density by 3-4 orders of magnitude compared to earlier attempts. We present the design and schematic of this new experimental setup and discuss its potential to finally observe and analyze these elusive quantum phenomena.

1. T. W. B. Kibble, J. Phys. A **9**, 1387 (1976).
2. W. H. Zurek, Nature **317**, 505 (1985).
3. V. B. Efimov, *et al.*, Phys. Rev. E, **74**, 056305 (2006).

TH5.21 Searching for Axions and Nonlinear QED with Superconducting RF Cavities

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Bogorad et al. proposed Superconducting Radio-Frequency (SRF) cavities with quality factors $Q \sim 10^{12}$ as a platform for detecting axions, which are a dark matter candidate, as well as low-energy QED corrections that give rise to photon-photon scattering. The idea is to use the cubic nonlinearity of axion-electrodynamics to detect the axion field by measuring photons at a signal frequency $\omega_3 = 2\omega_1 - \omega_2$ in an SRF cavity simultaneously pumped with photons at two resonant frequencies ω_1 and ω_2. Signal photons are sourced by axion-mediated currents, or by virtual electron-positron pairs in the vacuum of the cavity [1,2]. However, the Meissner screening current is a nonlinear function (nonlinear Meissner effect [NLM]) of the field at the surface, and thus sources photons at the signal frequency ω_3 [3]. We report calculations of the number of NLM photons, leakage noise photons, and the resulting impact on the sensitivity of SRF cavities to axion and QED mediated photon conversion. We also show that SRF cavities with ultra-high-$Q \sim 10^{22}$, the NLM effect parametrically shifts surface photons off the signal frequency and allows for detection of nonlinear QED conversion. Detection requires suppression of unbound electrons in the superconducting cavity and operational temperatures of $T \approx 0.1$ K. We also show that two-cavity setup for source and detector proposed by Gao and Harnik [4] may be suitable for detection of the axion field.

1. Bogorad, Z. et al., Phys. Rev. Lett. 123, 021801 (2019).
2. Heisenberg, W. and Euler, H., Z. Phys. 98, 714 (1936).
3. Sauls, J. A., Prog. Theor. Exp. Phys. 2022, 033I03 (2022).
4. Gao, C. and Harnik, R., J. High Energ. Phys. 2021, 53 (2021).

4.3 Oral Presentations: Friday 26th July

FR1.1 Recent progress in electron-on-solid-neon qubits

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Electron-on-solid-neon (eNe) is an emerging qubit platform. The performance of an eNe charge qubit has far exceeded that of the traditional semiconductor and superconductor charge qubits. [1,2] Here, we present our recent progress in this qubit platform. The electron-photon coupling strength has been enhanced to above 10 MHz, showing a great promise toward the realization of two-qubit gates. The temperature dependence up to 300 mK for the relaxation and coherence times has been measured, indicating a clear advantage over superconducting transmon qubits according to their reported data.

1. X. Zhou *, X. Li *, Q. Chen, G. Koolstra, G. Yang, B. Dizdar, Y. Huang, C. S. Wang, X. Han, X. Zhang, D. I. Schuster, and D. Jin, "Electron charge qubit with 0.1 millisecond coherence time", Nat. Phys. 20, 116–122 (2024).
2. X. Zhou, G. Koolstra, X. Zhang, G. Yang, X. Han, B. Dizdar, X. Li, R. Divan, W. Guo, K. W. Murch, D. I. Schuster, and D. Jin, "Single electrons on solid neon as a solid-state qubit platform", Nature 605, 46–50 (2022).

FR1.2 Progress in readout and control of an electron qubit floating on helium

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EeroQ Corporation, USA

Electrons floating on liquid helium can be excellent building blocks for a quantum computer, due to their scalability and long expected coherence times, particularly for the electron spin state. The first step to quantum computing with electrons on helium requires readout of the electron's in-plane motional state, which acts as a gateway to the electron spin state. The hallmark of a coherent motional state is the observation of so-called strong coupling, which has been highly sought-after for the last decade. In this talk, I will discuss EeroQ's general approach in the quest for strong coupling to the motional state of an electron on helium. Our recent experimental results have led to new insights on interactions between electrons and the superfluid helium surface, and I will discuss ways to control this interaction. Our efforts to increase the coupling and reduce noise sources will pave the way to quantum computing with electrons on helium.

FR1.3 Plasmon-photon coupling using electrons on helium

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Surface electrons (SEs) floating above liquid helium form a 2-dimensional system of electrons, which exhibits longitudinal long-range collective modes of motion known as plasmons[1]. We demonstrate the coupling of the radial plasmon modes of a 2D electron disc containing $> 10^7$ electrons to a lumped element LC circuit (resonant frequency $\approx$ 121 MHz, loaded Q-factor $\approx$ 300) in both the Wigner crystal and electron liquid phases.
The SEs are confined to a disc between two sets of Corbino electrodes that form a parallel plate capacitor, which is connected to a superconducting micro-inductor. The plasmon frequency is determined by the radius of the SE disc and hence can be tuned by the potential applied to the Corbino electrodes. When a plasmon mode's frequency is tuned on resonance with the LC circuit we observe avoided crossing behaviour. By applying microwaves we demonstrate the plasmons can be used to enhance the sensitivity of a Rydberg detection scheme using RF reflectometry of the LC circuit, and discuss their potential in quantum information applications[2].

1. C.C. Grimes and G. Adams, Phys. Rev. Lett. **36**, 145 (1976).
2. Kawakami et al., Phys. Rev. Appl. **20**, 054022 (2023)

FR1.4 Hybrid circuit QED platform between a transmon and an electron-on-solid-neon charge qubit

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The motional states of a single electron floating on a thin film of solid neon at cryogenic temperatures can reach coherence times several orders of magnitude longer than traditional charge qubits in semiconductor devices due to a longer physical distance between the electron and material defects within the substrate. In this talk we describe the preliminary characterization of a hybrid device that is capable of coupling such an electron charge qubit to a superconducting transmon qubit through virtual photons in a shared resonator bus. Our work marks the first steps towards a long-lived electron spin memory on solid neon interfaced with traditional superconducting-circuit-based quantum processors.

FR1.5 Single-Electron Qubits Based on Quantum Ring States on Solid Neon Surface

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Recent experiments have indicated the potential of a single electron bound to a solid neon surface as a charge qubit with an exceptionally long coherence time, making it a highly promising platform for quantum computing. However, certain observations have raised questions on the correlation between the electron's binding mechanism and its quantum states with the applied electric trapping potential. This study introduces a theoretical framework to examine the interactions of the electron with the topography of the neon surface, including its bumps and valleys. For extensive topographical variations, the Schr odinger equation for the electron's lateral motion on the curved 2D surface is solved to gain deeper insights. Our results show that surface bumps can naturally bind an electron, creating unique ring-shaped quantum states that align with experimental observations. Additionally, we show that a magnetic field can smoothly tune the electron's excitation energy to facilitate qubit operation. This study represents a significant advancement in our understanding of e-neon qubit properties, laying the groundwork for developing this technology to advance quantum computing architectures.

1. T. Kanai, D. Jin, and W. Guo, "Single-Electron Qubits Based on Quantum Ring States on Solid Neon Surface," *Phys. Rev. Lett.* **132**, 250603 (2024)

FR2.1 Cooling, noise mitigation, and decoherence in quantum circuits immersed in a quantum fluid bath

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The measured properties of superconducting quantum circuits appear to plateau out far above the dilution refrigerator base temperature, under usual thermalization schemes. This motivated our study of such circuits immersed in a quantum fluid bath of liquid He-3, cooled to below 1 mK. The first results on superconducting quantum resonators demonstrated not only cooling, but also significant reduction in noise, indicating coupling between the He-3 and two level systems/fluctuators[1]. This has opened a new route for understanding and mitigating noise in quantum processors. A quantum testbed, exploiting our cryogen-free adiabatic nuclear demagnetization refrigerator[2], has been constructed to study individual qubits, and resonators and first results will be reported.

1. Lucas, M. et al. Nat. Comms. (2023)14.3522
2. Nyeki, J. et al. Phys. Rev. Applied **18**, L041033 (2022)
We acknowledge current support by UKRI EP/Y022627/1 and funding from the EU Horizon 2020; grant agreement no. 824109 (European Mictokelvin Platform).

FR2.2 Evidence for Bose-Einstein condensation of vacancies in helium adsorbed on a carbon nanotube

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Supersolidity has been predicted by Andreev and Lifshitz already 50 years ago [1]. This phenomenon was proposed to occur in quantum solids, like helium crystals, where, at low enough temperatures appear a Bose-Einstein condensation (BEC) of defects like vacancies. Such a solid, called supersolid, would possess at the same time a property of superfluid liquid, and a translational symmetry, a property of crystal. However, in balk solids supersolidity has not been ever observed because vacancies disappear at low temperatures because of high activation energy. Nevertheless, solid helium adsorbed on carbon nanotube generally always contain significant number of vacancies. These vacancies are topologically imposed due to the mismatch between carbon sub-lattice and the lattice of helium solid. In our previous work we have shown that vacancies delocalize at temperatures below 0.1 K [2]. Here we describe a manifestation of BEC of mobile delocalized vacancies. The supersolidity has been detected as an increase of the dissipation of the oscillations of suspended nanotube with adsorbed helium on it. Temperature of the transition was in perfect agreement with the theoretical estimates.

1. A. F. Andreev, I. M. Lifshitz, Quantum theory of defects in crystals. Sov. Phys. JETP 29, 1107 (1969). 2. I. Todoshchenko, M. Kamada, J.-P. Kaikkonen, Y. Liao, A. Savin, M. Will, E. Sergeicheva,T. S. Abhilash, E. Kauppinen, P. Hakonen, Topologically-imposed vacancies and mobile solid 3He on carbon nanotube. Nat. Commun. 13, 5873 (2022).

FR2.3 Superfluid phase transition of nanoscale-confined helium-3

C. Sun, A. Attar, and I. Boettcher

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We theoretically investigate the superfluid phase transition of helium-3 under nanoscale confinement of one spatial dimension realized in recent experiments. Instead of the 3 x 3 complex matrix order parameter found in the three-dimensional system, the quasi two-dimensional superfluid is described by a reduced 3 x 2 complex matrix. It features a nodal quasiparticle spectrum, regardless of the value of the order parameter. Our analysis is based on a study of the two-body Cooper problem, mean-field theory, and renormalization group theory.

1. Sun, Attar, Boettcher, Phys. Rev. B 108, 144503 (2023)

FR2.4 Friedel Oscillations in One-Dimensional Superfluid ^{4}He

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One-dimensional bosonic systems, such as helium confined to nanopores, exhibit Luttinger liquid behavior characterized by density waves as collective excitations. In this study, we investigate the impact of hourglass-shaped constrictions, found in real experimental nanopores, on a quasi-one-dimensional superfluid. We consider a microscopic model of ^{4}He inside a perturbed nanopore with a localized constriction, and employ quantum Monte Carlo simulations to analyze the density of the core within an effective low-energy framework. Our results reveal the emergence of Friedel oscillations in a bosonic superfluid without a Fermi surface. Furthermore, we utilize the Luttinger liquid model to predict experimentally observable signatures of this pinning phenomena in elastic scattering and via the temperature and pressure dependence of mass transport through the deformed nanopore.

This work was supported in part from the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Award Number DE-SC0024333.

FR2.5 Superfluidity of ^{4}He films adsorbed on hexagonal boron nitride

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Recent studies claim that the second atomic layer of ^{4}He films adsorbed on graphite exhibits a fascinating coexistence of superfluid and crystalline orders[1]. Since the coexistence should be sensitive to the magnitude of the periodic substrate potential, experiments employing an alternative substrate with shallower potential will shed light on the physics of the multiple symmetry breaking. Hexagonal boron nitride (hBN) is such a candidate[2]: One may expect emergence of superfluidity in adsorbed ^{4}He at lower coverages than on graphite. Here we present the first result of the measurement of superfluidity of ^{4}He films on hBN. The superfluid response is measured by a torsional oscillator containing a pellet of hBN flakes[3]. Ordinary BKT-type superfluid transitions have been observed at coverages from about 16 atoms/nm^2, i.e. in the second layer. Comparing with the result on graphite, in which the BKT superfluid phase is observed only in the third layer[4], our result on hBN suggests that the effect of the periodic potential is so weak that the coexistence phase is absent, or it may emerge at lower coverages, even in the first layer. Detailed measurements are underway.

1. J. Nyeki *et al.*, Nature Phys. **13**, 455 (2017); J. Choi *et al.*, Phys. Rev. Lett. **127**, 135301 (2021).
2. P. L. Silvestrelli *et al.*, J. Low Temp. Phys. **196**, 42 (2019); S. Moroni *et al.*, Phys. Rev. B **103**, 174514 (2021).
3. UHP-S2 hBN flake, Resonac Co. (ex. Showa Denko Co.)
4. P. A. Crowell and J. D. Reppy, Phys. Rev. B **53**, 2701 (1996).

FR3.1 A proposal for detecting the spin of a single electron in superfluid helium

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The electron bubble in superfluid helium has two degrees of freedom that may offer exceptionally low dissipation: the electron's spin and the bubble's motion. If these degrees of freedom can be read out and controlled with sufficient sensitivity, they would provide a novel platform for realizing a range of quantum technologies and for exploring open questions in the physics of superfluid helium. I will propose here a practical scheme for accomplishing this readout and control by trapping an electron bubble inside a superfluid-filled optoacoustic cavity.

[1] J. Ma, YSS Patil, J. Yu, Y. Wang, and JGE Harris, arXiv:2308.07174 (2023)

FR3.2 Observation of Duffing Non-Linearity in a Superfluid Sonic Crystal

S. Kumar, M. Kenworthy, T. Speake, S. Hibbitt, and X. Rojas

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We report measurements of a nanoscale superfluid ^{4}He acoustic resonator, which is an acoustic mode confined within a sonic crystal's defect. This type of geometry offers promising prospects for superfluid optomechanical systems [1]. Our measurements show a temperature dependence of the resonance frequency, which provides new insights into the sound velocity within this unique geometry. We also explore the sound attenuation consistent with three-phonon scattering and ^{3}He impurities scattering. Furthermore, the nanoscale confinement enabled the first observation of a duffing nonlinearity in a superfluid acoustic resonator. Finally, we will discuss our latest progress in thin-film superfluid optomechanical systems.

[1]. Spence, S. *et al.* (2021). "Superfluid Optomechanics With Phononic Nanostructures". Phys. Rev. Applied, **15**, 034090

FR3.3 Quasiparticle Creation and Annihilation using a Single Manipulable Superconducting Vortex

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We introduce the Single Vortex Box (SVB) - a nanodevice that allows to treat a single superconducting vortex as a macroscopic particle, which can be created and annihilated with pulses of electrical current. Using the method of fast nanosecond-resolving switching thermometry[1], we measure the temperature rise and the subsequent thermal relaxation resulting from the expulsion of just a single vortex out of the SVB[2]. Our experiment provides a calorimetric estimation of the dissipation in a superconductor due to a single moving vortex. In another experiment we analyze diffusion of quasiparticles (QPs) in the narrow strip connecting a heater and a nanobridge which serves as a detector of QPs. The strip contains the SVB in the middle of its length. It allows for hosting a single vortex which enters the box at well-defined magnetic field $B_\perp$ [2,3]. When the heater is excited with a current pulse, we observe suppression of the switching current I_{sw} of the bridge due to excess quasiparticles travelling along the strip. In the $I_{sw}(B_\perp)$ dependencies we identify steps corresponding to the annihilation of QPs with a single or two superconducting vortices present in the box. We thus can see the single vortex by the influence it exerts on the flux of diffusing quasiparticles. Our experiments are pivotal steps towards the development of the vortex electronics i.e. memory cells, superconducting diodes, logical elements, and heat valves.

1. Zgirski, M., et al., Phys. Rev. Applied 14, 044024 (2020)
2. Foltyn, M., et al., arXiv:2402.06427 (2024)
3. Foltyn, M., et al.,Phys. Rev. Applied 19, 044073 (2023)

FR3.4 All-metallic gate-tunable superconducting microwave resonators

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[c]Department of Physics, POSTECH, Pohang, South Korea
[d]Agency For Defense Development, Daejeon, South Korea

Hybridizing a microwave mode with a quantum state requires precise frequency matching of a superconducting microwave resonator and the corresponding quantum object. However, fabrication always brings imperfections in geometry and material properties, causing deviations from the desired operating frequencies. An effective and universal strategy for their resonant coupling is to tune the frequency of a resonator. Here, we demonstrate gate-tunable, titanium-nitride (TiN)-based superconducting resonators by implementing a nanowire inductor whose kinetic inductance is tuned via the gate-controlled supercurrent (GCS) effect. We investigate their responses for different gate biases and observe 4% frequency tuning [1]. We also perform temperature-controlled experiments to support phonon-related mechanisms in the GCS effect and the resonance tuning. The GCS effect-based method proposed in this study provides an effective route for locally tunable resonators that can be employed in various hybrid quantum devices.

[1] Y. Ryu *et al.* Nano Lett. 24(4), 1223-1230 (2024).

FR3.5 Detecting induced unconventional superconductivity with cQED

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Hybrid systems represent one of the frontiers in the study of unconventional superconductivity and are a promising platform to realize topological superconducting states. Owing to their mesoscopic dimensions, these materials are challenging to probe using many conventional measurement techniques, and require new experimental probes to successfully characterize. In this talk, we discuss a probe that enables us to measure the superfluid density of micron-size superconductors using microwave techniques drawn from circuit quantum electrodynamics (cQED). We apply this technique to a paradigmatic hybrid system, the superconductor/ferromagnet bilayer, and find signatures of induced triplet pairing with a nodal p-wave order parameter[1]. Moreover, we unexpectedly observe drastic modifications to the microwave response at frequencies near the ferromagnetic resonance, suggesting a coupling between the spin dynamics and induced superconducting order in the ferromagnetic layer. Finally, we will discuss future routes for exploring spin dynamics in triplet superconductors[2].

1. C. Bottcher, N. Poniatowski, A. Grankin, M. Wesson, Z. Yan, U. Vool, V. Galitski, A. Yacoby, arXiv:2306.08043 (to appear in Nat. Phys., 2024).
2. N. Poniatowski, J. Curtis, C. Bottcher, V. Galitski, A. Yacoby, P. Narang, E. Demler, Phys. Rev. Lett. 129, 237002 (2022).

4.4 Poster Presentations: Friday 26th July

FR4.1 Accelerator cavity quench spot detection using particle tracking velocimetry

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Superconducting Radio-Frequency (SRF) cavities cooled by Superfluid Helium-4 (He II) are critical components of modern particle accelerators. Surface defects in SRF cavities can induce Joule heating, leading to cavity quenching. Current methods for detecting quench spots, such as temperature mapping and second-sound trilateration, face limitations in precision and practicality. Our lab has demonstrated an alternative detection method based on Molecular Tagging Velocimetry (MTV) in He II, which offers significantly improved spatial resolution[1]. However, due to the complexity of the required laser facility, this method is challenging to implement in accelerator labs. Here, we discuss a new method based on Particle Tracking Velocimetry (PTV) using solidified deuterium (D_2) tracer particles. A preliminary experiment is conducted with a miniature heater in He II to emulate a cavity quench spot. Our results show that the velocity field of the tracer particles near the heater can accurately locate the heater's position. Given the simplicity of the PTV setup, this method could be a promising alternative for implementation in accelerator labs.

1. Bao, S., Kanai, T., Zhang, Y., Cattafesta III, L. N., Guo, W. (2020). "Stereoscopic detection of hot spots in superfluid ^{4}He (He II) for accelerator-cavity diagnosis". International Journal of Heat and Mass Transfer,161, 120259.

FR4.2 On the Development of a 2-D LC Detection System for Flying Balls in Superfluid Helium

M. Arrayás, C. C. E. Elmy, D. Field, A. Gheorghe, R. P. Haley, Š. Midlik, E. Mobbs-Pursell, R. Schanen, D. E. Smart, S. Soulerin, J. L. Trueba, C. Uriarte, V. V. Zavjalov, and D. E. Zmeev

We have developed a novel device designed to probe superfluid ^{3}He and ^{4}He by magnetically levitating and manoeuvring a superconducting sphere of lead within the superfluid. A variety of motion patterns have been achieved including simple harmonic oscillations, uniform linear motion and circular motion; the latter of which facilitates a multitude of new approaches to research quantum turbulence and the dynamics of Andreev bound states on the edges of topological superfluid ^{3}He-B.
Preliminary measurements tracked the position of the ball via an optical camera; however, this method would be unfeasible within a dilution refrigerator. To overcome this, an LC detection system has been developed. The LC circuit is comprised of two detection coils, each corresponding to a different axis. These two coils give rise to two distinct resonances, the signal from which is measured via a multi-demodulator lock-in amplifier. Two transmission coils are positioned opposite the detection coils and are driven at the resonant frequencies of the LC circuit. The flying ball is situated between the transmission and detection coils, such that it is surrounded by coils on all four sides.
The dependence of the signal on the position of the ball is governed by two distinct effects: the changing mutual inductance between the transmission and detection coils; and the changing inductance of the detection coils due to the diamagnetism of the ball. Finite element analysis has been used to map the amplitudes of each resonance to the 2-D position of the ball. This has been validated against video data, successfully demonstrating the viability of the LC detection circuit and allowing future research to take place within a dilution refrigerator.

FR4.3 Cooling a 1D quantum wire using a liquid ^{3}He immersion cell

Rasul Gazizulin[a,b], Mingyang Zheng[a], Rebika Makaju[a], Chao Huan[a,b], Alexander M. Donald[a,b], Nicolas Silva[a,b], Christopher J. Ollmann[a,b], Mark W. Meisel[a,b], and Dominique Laroche[a]

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Effective thermalization techniques, low-pass filtering of the measurement lines, and an electromagnetically quiet environment are required to achieve ultra-low electron temperatures in the range of a few millikelvin. This study outlines enhancements, implemented on a commercial dilution refrigerator, Bluefors LD250, with a base temperature of less than 10 mK, which facilitate the effective reduction of electron temperature within a one-dimensional system, approaching the base temperature of the mixing chamber as determined from the drag signal between two quantum wires. The design of a new liquid ^{3}He immersion cell which extends earlier versions [1] will be presented. This setup enables electron transport experiments in a variety of low-dimensional electron systems.

[1] J.S. Xia *et al.*, Physica B **280** (2000) 491, https://doi.org/10.1016/S0921-4526(99)01843-8

The National High Magnetic Field Laboratory (NHMFL or MagLab) is supported by the National Science Foundation (NSF) through cooperative agreements DMR-1644779 and DMR-2128556, and the State of Florida. This work was partially supported by the NHFML User Collaboration Grants Program (UCGP).

FR4.4 Probing Quantum Phenomena using Bay 2 of the High B/T Facility

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Magnetic measurement is a powerful way to study novel quantum properties of condensed matter at ultra-low temperature, *i.e.* quantum spin liquid, quantum critcality, and low dimensional interactions. Equipped with a dilution refrigerator/Cu nuclear demagnetization refrigerator system, Bay 2 of the High B/T Facility of the Maglab provides our users with experimental conditions at ultra-low temperature (down to 500 μk) and in high magnetic field (up to 8 Tesla). Taking advantage of the ultra-quiet electronic environment and vibration free condition, our users can apply cutting edge techniques to explore the extremes in the parameter space of their samples. This presentation will also report on several recent ultra-low temperature experiments conducted at Bay 2, including nuclear magnetic resonance (NMR) experiments on a quasi-one-dimensional system, AC susceptibility measurements of a quantum spin liquid candidate compound and the quantum critical point of $TmVO_4$.

The National High Magnetic Field Laboratory (NHMFL or MagLab) is supported by the National Science Foundation (NSF) through cooperative agreements DMR-1644779 and DMR-2128556, and the State of Florida. This work was partially supported by the NHFML User Collaboration Grants Program (UCGP).

FR4.5 Pairing and excitation structure of an odd-frequency superfluid Fermi gas

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[b]Department of Basic Science, Tokyo University, Japan

We theoretically discuss strong-coupling properties of an odd-frequency Fermi superfluid[1]. This state has the following two features: (1) Cooper pairs are formed between fermions at *different times*, rather than at the same time. (2) The single-particle excitation spectrum is gapless. Using the path integral scheme[2,3] of the BCS-Eagles-Leggett mean-field theory[4,5], we investigate the space-time structure of the odd-frequency Cooper-pair wavefunction at $T = 0$, to clarify whether the *unequal-time* Cooper pairs still behave like bosons. We also consider the temperature dependence of the nuclear spin-lattice relaxation rate T_1^{-1}, to compare our results with the recently observed anomalous temperature dependence of T_1^{-1} in $CeRh_{0.5}Ir_{0.5}In_5$, which has recently attracted much attention as a candidate for the odd-frequency superconductivity[6].

1. S. Iwasaki, T. Kawamura, K. Manabe, and Y. Ohashi, Phys. Rev. A **109**, 063309 (2024). 2. D. Solenov, I. Martin, and D. Mozyrsky, Phys. Rev. B **79**, 132502 (2009). 3. H. Kusunose, Y. Fuseya, and K. Miyake, J. Phys. Soc. Jpn. **80**, 054702 (2011). 4. D. M. Eagles, Phys. Rev. **186**, 456 (1969). 5. A. J. Leggett, in *Modern Trends in the Theory of Condensed Matter* ed. by Pekalski and Przystawa (Springer, Berlin, 1980) p.14. 6. S. Kawasaki, T. Oka, A. Sorime, Y. Kogame, K. Uemoto, K. Matano, J. Guo, S. Cai, L. Sun, J. L. Sarrao, J. D. Thompson and G.-q. Zheng, Commun. Phys. **3**, 148 (2020).

FR4.6 New experimental platform for two-dimensional helium film adsorbed on a graphene substrate

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We propose a graphene-based cavity electromechanical system as an experimental platform for studying helium thin films. Despite its appealing physical properties, graphene substrates have not been experimentally utilized to explore the physical characteristics of adsorbed helium. Due to its structural advantage, our system is expected to offer higher sensitivity compared to previous experimental techniques.
In our approach, the mass and stiffness of helium films are directly reflected in the resonance frequency and dissipation of a graphene mechanical resonator. The properties of the graphene resonator are measured using a capacitively coupled microwave coplanar waveguide, which allows for strong optomechanical coupling due to the large graphene membrane. We present the progress on the fabrication process and characterization of our on-chip devices. We expect that this measurement scheme can serve as an ultimate platform for studying the 2D nature of quantum gases.

FR4.7 Methods to verify inertia of a quantum vortex in superfluid atomic gases

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Recently, in ultracold atomic gases, a box potential has been feasible and thus we can precisely control the vortex dynamics in uniform superfluids [1,2]. Two-dimensional flows in superfluids of ^{4}He and cold atoms have been described by the point vortex model. In this model, the inertia of vortices, the vortex mass, was assumed to be very small and often neglected in the literature. Even though various theoretical models are proposed, the vortex mass has been never verified and is a long-standing problem in low temperature physics. This is partly because spatial inhomogeneity due to a conventional potential, *e.g.* a harmonic trap, makes it difficult to observe its impact precisely. In this study, we investigate dynamics of massive point vortices in uniform superfluids and quantitatively reveal the fundamental impacts of the vortex mass on their dynamics at absolute zero without the mutual friction. We propose efficient ways to measure and verify the vortex mass in cold atoms trapped in a box potential.

[1] W. J. Kwon, *et. al.*, Nature **600**, 64–69 (2021).
[2] D. Hernández-Rajkov, *et. al.*, Nature Physics (2024).

FR4.8 Comparison of RF reflectometry and image charge detection for quantum state detection of electron on helium

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Quantum state detection of electrons on helium promises advancements in quantum computing. This study conducts a comparative analysis between radio frequency (RF) reflectometry[1] and image charge detection[2] methods. RF reflectometry detect changes in impedance induced by electron transitions between Rydberg states, offering high sensitivity and potential for rapid qubit-state readout. On the other hand, image charge detection identifies changes in electron height due to Rydberg transition. Cryogenic amplification is employed to enhance sensitivity and bandwidth. Calibrating its trans-impedance gain[3] allows us to determine the number of electrons in the first excited Rydberg states across various microwave attenuation settings. We demonstrate the differences in response to microwave attenuation, electron numbers, and potential confinements between the two methods. Our analysis provides valuable insights into the strengths and limitations of each approach, facilitating researchers in selecting the optimal method for diverse quantum computing applications.

1. F. Vigneau et. al. (2023). "Probing quantum devices with radio-frequency reflectometry". Appl. Phys. Rev. 10, 021305.
2. E. Kawakami, A. Elarabi, and D. Konstantinov (2019). "Image-Charge Detection of the Rydberg States of Surface Electrons on Liquid Helium". Phys. Rev. Lett. 123, 086801.
3. M. Belianchikov, J. A. Kraus, and D. Konstantinov (2024). "Cryogenic Resonant Amplifier for Electron-on-Helium Image Charge Readout". J. Low Temp. Phys. doi.org/10.1007/s10909-023-03033-6.

FR4.9 NMR Measurements of Helium Three on Graphite Plated with Bilayer of HD

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In some quantum spin systems on two-dimensional (2D) lattices with geometrical frustration, the ground state is expected to be a quantum spin liquid. One unique and promising example is helium three (^{3}He) monolayers adsorbed on graphite. Recent heat-capacity measurements suggest the existence of two different kinds of spin liquid states in this 2D nuclear spin system, where one may involve elementary excitations of Majorana fermions and the other a peculiar quantum structure, the quantum liquid crystal. Apparently, more comprehensive experimental information is needed to clarify these fascinating possibilities.
We have started a new series of nuclear magnetic resonance (NMR) measurements of this system down to microkelvin temperatures. Specifically, we employ graphite coated with a bilayer of hydrogen-deuterium (HD) to weaken the adsorption potential of the substrate and promote competition among multi-particle exchanges of ^{3}He atoms. We are planning to measure the magnetization with continuous-wave NMR and the spin-spin relaxation time, which will provide us information on spin dynamics, with pulsed NMR as functions of temperature and ^{3}He coverage.
We are currently at the stage where the fabrication of a sample cell for the NMR measurements has been completed, and a measurement of the adsorption surface area of graphite at nitrogen temperature has been finished.

FR4.10 Charge Density Domain Formation in Microwave-Excited Two-Dimensional Electron System on Liquid Helium

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Electrons on the surface of liquid helium form ultraclean two-dimensional (2D) electron system and provide an ideal platform to study various physical phenomena in two dimensions. When subjected to resonant microwave irradiation and perpendicular magnetic fields, this system exhibits numerous non-equilibrium phenomena[1], including microwave-induced resistance oscillations (MIRO), zero-resistance states (ZRS), incompressible electronic behavior, and self-generated audio-frequency oscillations.
Here we report the study of MIRO and ZRS in 2D electron system on liquid helium, utilizing edge-magnetoplasmon (EMP) spectroscopy. Our experiments reveal a narrowing of EMP spectra under resonant microwave irradiation and the conversion of conventional EMP modes to novel modes when magnetoresistance disappears. These results provide evidence of charge density domain formation in the zero-resistance state and enable the characterization of parameters associated with these density domains.

1. Yu. Monarkha and D. Konstantinov J. Low Temp. Phys. 197, 208 (2019).

FR4.11 Strong-coupling properties of a spin-orbit coupled ultracold Fermi gas and effects of rashbon bound states

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Since the realization of a Raman-type spin-orbit coupling in 2012,[1] the so-called Rashba-type spin-orbit coupling (RSOC) has been explored in cold Fermi gas physics. RSOC is predicted to bring about the formation of two-body bound states, which is sometimes referred to as "rashbons" in the literature, even when the strength of a pairing interaction between fermions is very weak.[2] We theoretically discuss how rashbons affect normal-state properties of a spin-orbit-coupled ultracold Fermi gas over the entire BCS-BEC crossover region. Within the framework of the strong-coupling theory developed by Nozières and Schmitt-Rink (NSR), we calculate the specific heat C_V. From the detailed analysis on the temperature dependance of C_V, we identify the region where rashbons dominate over system properties, as well as the region where fluctuating rashbons are crucial, in the phase diagram with respect to the spin-orbit coupling strength, pairing interaction strength, and temperature.[3]

1. Wang, P., Yu, Z., Fu, Z., Miao, J., Huang, L., Chai, S., Zhai, H. and Zhang, J. Phys. Rev. Lett. 109(9), 095301 (2012).
2. Vyasanakere, J., Shenoy, V. Phys. Rev. B 83(9), 094515 (2011).
3. Okajima, Y., Takemoto, K., Iwasaki, S. and Ohashi, Y. Phys. Rev. A, in preparation.

FR4.12 Vacuum Break in a Helium Cooled Tube with an Inserted Cavity

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During a particle-accelerator beamline tube vacuum break, air rushes into the liquid helium cooled tube and condenses on the inner walls. This induces a substantial heat load onto the liquid helium and causes rapid boiling and potentially a dangerous pressure buildup. To better understand the intricate dynamical process, we have conducted systematic experimental studies and modeling using a tube cooled with liquid helium, both normal liquid helium (He I) and superfluid h elium (He I I). R esults indicated a nearly exponential slowing down of the gas propagation front[1,2]. We report the effect o f a n added cylindrical copper cavity with approximately the same diameter-to-length ratio as a representative of elliptical beamline cavities. Observations indicated that the gas would propagate past the cavity before fully filling the c avity[5]. This work provides new information toward a full understanding of vacuum break in particle accelerators.

1. N. Garceau, S. Bao, and W. Guo, 2019. "Heat and mass transfer during a sudden loss of vacuum in a liquid helium cooled tube -Part I: Interpretation of experimental observations." Int. Journal of Heat and Mass Transfer, 129, pp.1144-1150.
2. N. Garceau, S. Bao, and W. Guo, 2021. "Heat and mass transfer during a sudden loss of vacuum in a liquid helium cooled tube-Part III: Heat deposition in He II". Int. Journal of Heat and Mass Transfer, 181, p.121885.
3. N. Garceau, S. Bao, and W. Guo, 2022. "Vacuum Break in a Helium Cooled Tube with an Inserted Cavity". Int. Cryogenic Engineering Conference and Int. Cryogenic Materials Conference (pp. 413-419). Singapore: Springer Nature Singapore.

FR4.13 The two body density matrix of a Luttinger liquid

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The n-body reduced density matrix (n-RDM) characterizes higher order correlations in many-body systems such as quantum fluids and solids. This quantity can be used to compute any n-body observable and is experimentally measurable. Analytically, the problem of computing higher order density matrices becomes increasingly challenging as the number of coordinates grows; however, within the Luttinger Liquid regime, correlation functions can be accessed through bosonization. In this talk, we outline the derivation of the exact 2-RDM from bosonization and map it to the J-V model of interacting, spinless fermions in one dimension, where the low-energy sector is describable by Luttinger liquid theory. We present an analytical result for density-density correlations, allowing for an investigation of the effects of a finite size lattice. Our results agree with those obtained from density matrix renormalization group calculations. Finally, we discuss the application of our expression for computing two-body observables such as the energy and the particle entanglement.

FR4.14

FR4.15 High-frequency dynamics of the liquid and solid phases of electrons on helium

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The Coulomb liquid and solid states of electrons floating above the surface of superfluid helium exhibit non-trivial spatial structure and high-frequency temporal dynamics. This is particularly true of the collective interaction between the electronic Wigner solid state and the bosonic field of capillary waves (ripplons) on the helium surface. Here we present high-frequency transport measurements of microchannel confined electrons on helium to probe the interaction between the electron system and the thermal ripplonic bath. The measurements are carried out over a wide range of frequency from $0.1 - 170$ MHz via capacitively coupled lock-in techniques. At frequencies above ~ 10 MHz a significant parasitic background contribution to the signal is present and we describe a compensation circuit used to cancel this signal enabling us to observe the high-frequency resonant emission of ripplons by the electron system.

This work was supported by NSF DMR-2003815.

FR4.16 Toward atomically flat solid neon films for scalable electron-on-neon quantum bits.

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Electron charge qubits are appealing candidates for solid-state quantum computing due to the ease of fabrication, control, and readout. The recently developed charge qubits based on motional states of electrons trapped on the surface of thin solid neon films (eNe) outperform all the traditional charge qubits in terms of coherence metrics, T_1 and T_2, even without a deep optimization[1,2]. Although notoriously hard[3], predictable deposition of nm-thick atomically smooth neon films will be a cornerstone for the future eNe architecture scaleup. In this work, we present our efforts on growing atomically flat nm-thick solid neon films via quench condensation and annealing processes as well as our initial attempt on integrating liquid neon microfluidics with superconducting quantum circuits.

1. X. Zhou *et al.*, Nature **605**, 46 (2022).
2. X. Zhou *et al.*, Nat. Phys. **20**, 116 (2024).
3. P. Leiderer, J Low Temp. Phys, **87**, 247 (1992)

FR4.17 Design and Simulation of a Copper Flake Demagnetization Cell

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To address the increased user demand for ultralow sample temperatures, unique ^{3}He immersion cells are employed in the MagLab High B/T Facility [1]. Inspired by previous modeling [2] and experimental results [3], the ^{3}He immersion cell is being extended to include a Cu flake demagnetization refrigerant for use on a dry cryogenic system equipped with a 14 T magnet. With this new cell coupled to a dilution refrigerator through a heat switch, the configuration has been modeled and simulated using COMSOL [4] to estimate the temperature profile before and after demagnetization. The simulations indicate the cell precools to 10 mK, by the mixing chamber, and subsequently cools to 2 mK via the demagnetization of the Cu refrigerant when assuming a background heat leak of 5 nW.

1. J.S. Xia *et al.*, Physica B **280** (2000) 491, `https://doi.org/10.1016/S0921-4526(99)01843-8`
2. R.C.M. Dow *et al.*, J. Low Temp. Phys. **47** (1982) 477, `https://doi.org/10.1007/BF00683988`
3. D.I. Bradley *et al.*, J. Low Temp. Phys. **57** (1984) 359, `https://doi.org/10.1007/BF00681199`
4. COMSOL Multiphysics v. 6.2, www.comsol.com, COMSOL AB, Stockholm, Sweden.

The National High Magnetic Field Laboratory (NHMFL or MagLab) is supported by the National Science Foundation (NSF) through cooperative agreement DMR-2128556 and the State of Florida. This work was partially supported by the NHMFL User Collaboration Grants Program (UCGP).

FR4.18 Superfluid optomechanics with lumped element LC cavities

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Superfluid helium is emerging as a promising platform for the implementation of optomechanical systems both in optical [1] and radiofrequency domains [2]. Here, we present a simple experiment in which we observed parametric coupling between superfluid acoustic resonance and a resonant LC circuit in the low end of the radiofrequency regime. This work serves as a proof of concept for an on-chip superfluid optomechanical setup, which could provide further insights into the intriguing thermodynamics of superfluid He II. To realize the full potential of the electromechanical readout and control of the mechanical motion, strong coupling and sideband resolution are required between acoustic and electromagnetic resonances. In our experiment, we were able to achieve this sideband resolved regime, in which the width of the LC resonance is less than the acoustic resonance frequency, with a setup consisting of an acoustic resonator that served as capacitance, connected in series with a room-temperature RF inductor, forming a resonant LC tank circuit. Optomechanically induced transparency was measured to estimate the coupling constant between the two resonators. Further, we show that dynamical backaction phenomena are observable, as the acoustic resonance frequency and damping can be tuned by adjusting the supplied LC driving signal.

[1] Shkarin, A. B. *et al.* Quantum Optomechanics in a Liquid. Phys. Rev. Lett. 122, 153601 (2019).
[2] Spence, S. *et al.* Three-tone coherent microwave electromechanical measurement of a superfluid Helmholtz resonator. Appl. Phys. Lett. 123, 114001 (2023).

FR4.19 Density-wave instability and collective modes in a bilayer of soft-core fermions

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We study the dynamics of a bilayer system of fermions with repulsive soft-core Rydberg-dressed interactions within the mean-field random-phase approximation. We study the symmetric and antisymmetric collective density modes of the symmetric (equal density) bilayer and find that the dispersion of the modes signals the emergence of the density wave instability. Depending on the density of fermions in each layer, interaction strength, and the spacing between two layers, the homogeneous superfluid phase becomes unstable in either (or both) of these two channels, leading to density and pseudo-spin-density wave instabilities in the system.

FR4.20 Density Functional Theory of Rydberg-Dressed Bosonic Atoms in a Harmonic Trap

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The density functional theory of a system of Rydberg-dressed bosons in a harmonic trap is developed. The interaction between Rydberg-dressed atoms are modeled by a soft-core potential. We use the numerically accurate ground-state energy[1] of a uniform system of Rydberg-dressed bosons and treat the external harmonic potential within the local density approximation. Using a Runge-Kutta integrator and imaginary-time evolution, we calculate the ground state energy of the many-particle, harmonically confined interacting boson gas. We also calculate the breathing mode frequency by introducing a small perturbation to the trap potential and evolving the density in real time. We present our results depicting trends in the behavior of ground state energies and breathing frequencies as a function of relevant parameters such as the extent and the strength of the soft-core potential.

1. Seydi, I., Abedinpour, S.H., Zillich, R.E., Asgari, R., and Tanatar B. (2020). "Rotons and Bose condensation in Rydberg-dressed Bose gases", Phys. Rev. A **101**, 013628.

FR4.21 Potential flow of "superfluid" ^{4}He through a nanometer-sized channel

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Flow characteristics of one-dimensional superfluids are expected to vary drastically depending on temperature, length scale, chemical potential difference, etc., due to its criticality.[1,2] We have measured the mass flow of liquid ^{4}He through a porous alumina membrane, which contains bundles of highly oriented 3.4-nm channels inside 100-nm alumina pores. We found that the flow velocity shows a power-law dependence on the pressure difference through the channel, even below the temperature (T_o) at which superfluid fraction was observed by the torsional oscillator. Its power exponent varies from 0.3 to 0.2 with decreasing temperature from T_o to the lowest temperature (0.1 K). This behavior cannot be explained by the size dependence of conventional critical velocity. It may come from the criticality of the Tomonaga-Luttinger liquid, where the correlation length diverges with decreasing temperature toward absolute zero.

1. Y. Vekhov, R. B. Hallock, Phys. Rev. Lett. **109**, 045303 (2012).
2. C. L. Kane, M. P. A. Fisher, Phys. Rev. Lett. **68**, 1220 (1992).

FR4.22 Relaxation of the highly mobile state of ^{4}He films due to superfluidity

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We measured the relaxation of a highly mobile state for three-atom-thick ^{4}He films on graphite using a 32 kHz quartz tuning fork. The relaxation time from the mobile to the sticking state τ obeys the Arrhenius law at high temperatures. As lowering temperature, τ reaches the order of 10^4 s. Further lowering temperature, the relaxation enhances rapidly below a certain temperature and deviates from the exponential decay in the early stages. Then, it becomes significantly faster at the superfluid transition temperature T_{KT}. We found that τ near the end of relaxation collapses into a single curve if scaled by T_{KT} and that the magnitude of deviation from the exponential decay is proportional to the 2D coherence length of the KT transition.

FR4.23 A Novel Device for Formation and Investigation of Impurity Helium Condensates Containing Stabilized Atomic Species

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We have designed and built a novel device for in situ preparation of impurity helium condensates (IHCs) containing stabilized free radicals, for study by the method of electron spin resonance (ESR). IHCs are a porous aerogel-like material formed by injecting admixtures of He and impurity gasses, e.g. H_2 or N_2, into bulk superfluid helium-4. When the gas mixtures are dissociated immediately before entering the superfluid, large quantities of free radicals and atomic species become stabilized in the resulting condensates. These IHCs have been studied extensively over the past 50 years, however limitations of the existing methodology has required forming the sample near the top of the cryostat, then moving the sample to the cryostat tail where the ESR cavity is located. By combining existing techniques used for creating cryogenic glass-metal seals, as well as employing a shielded helical resonator to dissociate the gasses, we are now able to form these condensates directly within the ESR cavity. As a result this new device will enable the study of the process of accumulation of stabilized atoms in IHCs. This allows the optimization of the atom accumulation process in achieving high concentrations of stabilized atoms, as well as to study electrons and metastable atoms captured in IHCs.

FR4.24 Sample preparation protocol for surface X-ray diffraction of sub-monolayer helium adsorbed on single-surface graphite

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We have recently conducted surface X-ray diffraciton (SXRD) investigations of submonolayer helium films on single-surface graphite, which can offer incomparable structural insights of them [1, 2]. The single-surface graphite, of which only the outermost surface interacts with helium, has a significantly smaller surface area than those of exfoliated graphite. That is a critical issue in a sample preparation different from the established approaches that utilize an exfoliated graphite with a large surface area. We have examined several protocols to optimize helium-film preparation in the SXRD cell including a relatively large dead volume and a buffer surface for precise areal density control.

[1] AY, et al., J. Low Temp. Phys. 208, 441 (2022); [2] AK et al., JPS Conf. Proc. 38, 011004 (2023).

FR4.25 TUNABLE RECTIFIED COULOMB DRAG BETWEEN QUANTUM WIRES

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Coulomb drag between coupled one-dimensional wires is a powerful tool to probe the physics of Luttinger liquids. In a Coulomb drag measurement, the signal arises solely from the coupling between the two 1D electrical circuits, and not their leads or reservoirs, hereby directly probing the inter-wire interactions. In this work, we present Coulomb drag measurements between vertically coupled GaAs/AlGaAs quantum wires separated vertically by a hard barrier of only 15 nm in width. Previous experiments have shown that 1D Coulomb drag can result from either charge rectification or momentum transfer, corresponding respectively to a symmetric and an antisymmetric component in the Coulomb drag signal. The device reported here exhibits gate tunable and temperature dependent symmetric and antisymmetric contributions to the drag signal. Our study opens the possibility of studying the physical mechanisms behind the onset of both momentum transfer and charge rectification drag in a single device.

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4.5 Oral Presentations: Saturday 27th July

SA1.1 Quantum-limit phenomena in rare-earth-based layered $EuZn_2As_2$ and $CsNdSe_2$

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Layered $EuZn_2As_2$ and $CsNdSe_2$ are candidate magnetic topological materials with the magnetism from the involved rare-earth elements. While Eu forms a square lattice with its moment orders antiferromagnetically below 19 K in $EuZn_2As_2$, Nd in $CsNdSe_2$ forms a triangular lattice thus never orders magnetically down to 0.04 K. By applying pulsed magnetic fields up to 60 T, spin reorientation is observed accompanied with giant magnetoresistance (MR) in $EuZn_2As_2$. After passing the first Landau level, the large linear MR occurs at high fields corresponding to the quantum limit. On the other hand, the application of the magnetic field leads to long-range magnetic ordering with the highest transition temperature at 0.3 K in $CsNdSe_2$, implying the quantum spin liquid ground state at the ambient condition. Our findings help understand the intimate relationship between magnetism and electronic topology in magnetic topological materials.

SA1.2 Observation of spin-triplet superconductivity in nonmagnetic $CoSi_2/TiSi_2$ heterojunctions

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Unconventional superconductivity and, in particular, spin-triplet superconductivity have been front and center of topological materials and quantum technology research. I will present our recent observations of spin-triplet pairing symmetry in nonmagnetic $CoSi_2/TiSi_2$ heterostructures. $CoSi_2$ films grown on silicon undergo a sharp superconducting transition at a critical temperature of about 1.5 K, while $TiSi_2$ is a diffusive normal metal down to at least 50 mK. We investigate the phase-sensitive conductance spectra using two independent and complementary types of superconductor/normal metal (S/N) heterostructures, *i.e.*, the $CoSi_2/TiSi_2$ S/N junctions and the so-called "T-shaped superconducting proximity structures." In both cases and the superconducting state, we have found zero-bias conductance peaks and signatures that point to two-component ($s + p$) superconductivity with a dominant spin-triplet p-wave superconducting pairing component.[1,2] I will also discuss the unusual normal-state electrical-transport properties of $CoSi_2$ films on silicon, including strong Rashba spin-orbit coupling and ultralow $1/f$ noise.[3] These appealing material properties may be useful for making superconducting devices and quantum circuits.

1. Chiu S. P., *et al.*, Sci. Adv. **7**, eabg6569 (2021)
2. Chiu S, P., *et al.*, Nanoscale **15**, 9179 (2023)
3. Chiu S. P., *et al.*, arXiv:2401.17601; Chinese Journal of Physics (in press)

SA1.3 Fractional Quantum Anomalous Hall Effect in Graphene

Long Ju

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The fractional quantum Hall effect observed in conventional two-dimensional electron gas at the semiconductor interface is a classic example of intertwined electron correlation and topology effects in condensed matter physics. It has been proposed that similar exotic states could exist at zero magnetic field, by engineering flat electronic bands with non-zero Chern numbers. Here we report the observation of integer and fractional QAH effects in a rhombohedral pentalayer graphene-hBN moiré superlattice. At zero magnetic field, we observed plateaus of quantized Hall resistance $R_{xy}= h/(\nu e^2)$ at $v = 1$, 2/3, 3/5, 4/7, 4/9, 3/7 and 2/5 of the moiré superlattice, respectively, accompanied by clear dips in the longitudinal resistance R_{xx}. R_{xy} equals $2h/e^2$ at $v = 1/2$ and varies linearly with v, similar to the composite Fermi liquid in the half-filled lowest Landau level at high magnetic fields. By tuning the gate-displacement field D and v, we observed phase transitions from composite Fermi liquid and FQAH states to other correlated electron states. Our system provides an ideal platform for exploring charge fractionalization and (non-Abelian) anyonic braiding at zero magnetic field, especially considering a lateral junction between FQAHE and superconducting regions in the same device.

SA1.4 Searching for signatures of non-trivial topology in diffusive multiterminal Josephson junctions

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Multi-terminal Josephson junctions (MTJJs), or devices with a ballistic normal metal with n superconducting contacts, have been proposed as artificial analogs of topological $n-1$ dimensional crystals, with the phase difference ϕ between two superconductors playing the role of the wave vector k in a crystal.[1] Topological behavior has also been predicted for diffusive MTJJs, where a diffusive normal metal is placed in contact with multiple superconducting contacts.[2] Here we report measurements of the resistance of diffusive 3-terminal MTJJs as a function of the phase differences between the superconductors. The resistance shows a rich periodic structure that reflects the opening and closing of gaps in the excitation spectrum of quasiparticles resulting from the modulation of the phase differences between the superconductors. We compare our results to theoretical predictions[3] of the resistance of such 3-terminal devices.

1. Riwar *et al.*, Nat. Comm. **7**, 11167 (2016).
2. Strambini *et al.*, Nature Nanotechnology **11**, 1055 (2016).
3. V. Chandrasekhar, Appl. Phys. Lett. **121**, 222601 (2022).

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SA1.5 Anomalous Hall Effects in Chiral Superconductors

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The search for superconductors that are electronic analogs of the chiral phase of ^{3}He is an active research direction. Leading candidates include UPt_3, Sr_2RuO_4, URu_2Si_2 MoS, SrPtAs, $LaPt_3P$ and others. Chiral superconductors exhibit novel properties that depend on the topology of the order parameter and Fermi surface, and—as we highlight—the structure of the impurity potential. We present the theory of anomalous (zero field) Hall transport and report theoretical results for the electronic contribution to thermal and electrical transport for chiral superconductors belonging to even or odd-parity E_1 and E_2 representations of the tetragonal and hexagonal point groups. The anomalous thermal Hall conductivity is shown to be sensitive to the winding number, ν, of the chiral order parameter via Andreev scattering that transfers angular momentum from the chiral condensate to excitations that scatter off the random potential. Our results provide quantitative predictions for analysis and interpretation of thermal and microwave measurements for superconductors predicted to exhibit broken time-reversal and mirror symmetries. Research supported in part by the NSF Grant DMR-1508730, and the U.S. DOE, Office of Science, NQISR Centers, Superconducting Quantum Materials and Systems Center (SQMS), contract no. DE-AC02-07CH11359.

1. V. Ngampruetikorn & J. A. Sauls, Anomalous Hall Effects in Chiral Superconductors, Front. Phys. 12 (2024) [https://arxiv.org/html/1911.06299v2].
2. V. Ngampruetikorn & J. A Sauls, Anomalous Thermal Hall Effect in Chiral Superconductors, PRL, 124, 157002, 2020 [https://doi.org/10.1103/PhysRevLett.124.157002].

SA2.1 The A-B phase transition of superfluid helium-3 in a stepped-height nanofluidic platform

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The mechanism behind the first-order phase transition between ^{3}He-A and ^{3}He-B has evaded explanation despite decades of both experimental and theoretical work. Cosmological analogues connect this fundamental problem of condensed matter physics with the possible early-Universe phase transitions and associated generation of gravitational waves, predicted in many extensions of the Standard Model of particle physics. Within the QUEST-DMC project, we have nanofabricated a novel stepped-height sample container with five 6.8 µm deep phase-transition chambers to gain access to the cosmologically relevant intrinsic nucleation mechanisms. Close to atomically smooth silicon walls together with a 75 nm deep isolation barrier surrounding these chambers ensure protection against any obvious sources of heterogeneous nucleation. The tiny volumes also ensure that the phase transitions triggered by ionising radiation are strongly suppressed. Here we report the experimental SQUID-NMR results, showing both strong supercooling of ^{3}He-A and superheating of ^{3}He-B, with stochastic processes dominating the phase transitions between the two. We report the discovery of non-monotonic temperature dependence of the lifetime of the supercooled ^{3}He-A at low pressure and discuss the possible causes.

SA2.2 Orientational transitions in Helium-3 imbibed in anisotropic aerogel

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Department of Physics and Astronomy, Northwestern University, USA

The nuclear magnetic resonance of superfluid ^{3}He imbibed in anisotropic aerogel is a powerful probe of the structure and orientation of the superfluid order parameter. Recent simulations of anisotropic silica aerogel have revealed small-scale planar-like and nematic-like structure, consistent with small-angle x-ray scattering measurements. This structure has been experimentally shown to strongly influence both the phase stability and order parameter orientation of imbibed superfluid ^{3}He. We discuss the influence of anisotropic impurity on the superfluid phase and the structure of the order parameter in the framework of Ginzburg-Landau theory. Anisotropic pairbreaking caused by aerogel impurities has the capacity to distort and orient the order parameter in a manner respecting the anisotropy of the structure. The distortion of the order parameter indicates a mechanism underlying the orbital flop, a sharp transition in the nuclear magnetic resonance frequency shift.

This work was supported by NSF DMR-2210112.

SA2.3 Vortex core transitions in ^{3}He-B: Answer to a 40-year-old puzzle

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In macroscopic systems with multi-component order parameters, including unconventional superfluids and superconductors, different types of quantized vortices may exist. Already more than 40 years ago, two types of nonsingular vortices were found in the B phase of superfluid helium-3, which were later identified as the double-core and the A-phase-core vortices. A transition between the two structures was observed using NMR measurements in a rotating cryostat. One feature of the experimental vortex phase diagram[1] has remained unexplained: around the pressure of 17 bar, the double-core vortex is observed both at low temperatures and at high temperatures close to T_c, while at intermediate temperatures the A-phase-core vortex is found. We present numerical calculations using the Ginzburg-Landau formalism that reproduce the experimental vortex phase diagram, including the re-entrant transition at low pressures. As distinct from previous numerical calculations focused on the vortex structures themselves,[2,3] we additionally calculate the energy barrier between the two metastable configurations, while taking the applied magnetic field into account. The pressures and temperatures where the energy barrier vanishes correspond well to the experimentally observed transition line in the phase diagram. We also provide a qualitative explanation for the increased stability of the double-core vortex near T_c.

1. J. P. Pekola et al, Phys. Rev. Lett. **53**, 584 (1984)
2. S. M. Laine et al, Phys. Rev. B **98**, 174516 (2018)
3. R. C. Regan et al, Phys. Rev. B **101**, 024517 (2020)

SA2.4 Superfluid He-3 in periodic aerogel structures

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Recent experiments[1] on superfluid He-3 placed into planar aerogel revealed constant magnetic susceptibility across a wide range of temperatures, that includes both A- and B- phases. This is a surprizing result, since the spin structure of these superfluid phases are different, and usually even used as probe to distinguish the bulk phases. However, superfluid properties are modified in confined geometries and near impurities, such as aerogel, due to presence of surface Andreev states. Andreev quasiparticle states near fully reflective surfaces are a manifestation of the topological properties of the superfluid, and they create special magnetic environment different from the bulk. By modeling planar aerogel as periodic structures with semi-transparent interfaces, we investigate the order parameter and quasiparticle spectrum, using the scattering matrix approach and quasiclassical technique. We show that the bound state spectrum is very different for semi-transparent and fully reflective interfaces, and we provide an estimate of conditions that would lead to a temperature-independent magnetic susceptibility in A- and B- phases.

This research is supported by NSF grant DMR-2023928.

1. Scott, J.W. et al (2023). "Magnetic Susceptibility of Andreev Bound States in Superfluid ^{3}He-B" Phys. Rev. Lett. **131** 046001

SA2.5 Paramagnetic response of superfluid ^{3}He-B in anisotropic aerogel: Anomalous proximity effect and Andreev bound states

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Recent NMR experiments in superfluid ^{3}He with stretched silica aerogels have observed anomalous behavior of magnetic responses at low temperatures.[1] Although the frequency shift confirms the phase transition to the B phase, the magnetic susceptibility does not exhibit the typical behavior of the disordered BW state. Instead, it was found to be enhanced from what was expected in the disordered BW state. Furthermore, simulations of diffusion-limited cluster aggregation demonstrate that stretching silica aerogel leads to the formation of large-scale planer structures perpendicular to the stretching axis.[2] Motivated by these experiments and simulations, we investigate the magnetic response of the B phase of superfluid ^{3}He, focusing on spatial modulation and the finite-size effect of nonmagnetic disorders. The spatial modulation of disorders can generate odd-frequency spin-triplet s-wave Cooper pairs, resulting in a negative contribution to the superfluid density and paramagnetic response. The nonmagnetic impurities with finite radii lead to the formation of the Andreev bound states on their surfaces, which can also contribute to paramagnetic responses.[3] In this presentation, we will explore how these two effects interact to enhance the magnetic response of the BW state anomalously.

1. J. W. Scott *et al.*, Phys. Rev. Lett. **131**, 046001 (2023).
2. M. D. Nguyen *et al.*, Nat. Commun. **15**, 201 (2024).
3. T. Mizushima, Phys. Rev. B **90**, 184506 (2014).

SA3.1 Quantum Circuits and Sensors with He-4: Superfluid Analogs of SQUIDs, FOGs, and Ring Lasers Gyroscopes

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I will discuss our preliminary experiments to realize a Josephson junction (JJ) for He-4 using a novel two-dimensional, nanoporous material.[1] This covalently bonded 2D crystal has an array of ~ 1 nm diameter pores, comparable to the zero-temperature coherence length of He-4, and can be suspended over micron-size apertures in SiN. The aim of this work is to produce a JJ structure which can be used in superfluid circuits at temperatures far below T_λ to realize devices such as SQUIDs, superfluid qubits, and other quantum devices. I will also discuss a possible alternate route to ultra-sensitive rotation sensors which does not require a junction structure or measurement of small, low frequency mass currents, and relies on the quantized motion and ultra-low acoustic loss of first sound in superfluid He-4.[2] The fact that acoustic waves propagate at the speed of sound relative to the fluid and that the motion of the fluid is quantized with respect to the non-rotating frame, should make an acoustic Sagnac effect possible. This approach may form acoustic analogues of the fiber-optic gyroscope (FOG) and the ring laser gyroscope. The low value of the speed of first sound creates long Sagnac time delays, and the ultra-low acoustic loss may make long path length sensing coils possible, both are key properties for high sensitivity to rotation.

1. Kissel, P., et al. (2014). "A nanoporous two-dimensional polymer by single-crystal-to-single-crystal photopolymerization," *Nature Chemistry* **6**, pp. 774-778.
2. De Lorenzo, L. A., and Schwab, K. C. (2017). "Ultra-High Q Acoustic Resonance in Superfluid ^{4}He." *Journal of Low Temperature Physics* **186**, pp. 233-240.

SA3.2 Exploring Fermi superfluids with strongly pinned vortices: Consequences for dynamics and thermodynamics

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In macroscopic quantum condensates, rotation of the superfluid component is allowed only via formation of quantized vortices. In the context of the two-fluid model, the superfluid component couples to the normal fluid via scattering of thermal quasiparticles from quantized vortices. In equilibrium, superfluid follows the motion of the normal fluid, minimizing the counterflow term $\propto |\mathbf{v}_\mathrm{n} - \mathbf{v}_\mathrm{s}|^2$. Consequentially, $\mathbf{v}_\mathrm{s}$ approaches $\mathbf{v}_\mathrm{n}$. The situation is drastically different when vortices experience strong pinning, allowing for stable flows with $\mathbf{v}_\mathrm{n} \neq \mathbf{v}_\mathrm{s}$. In superconducting wires, engineered vortex pinning sites allow significantly higher critical currents as ohmic losses are related to vortex motion. Similarly, vortex pinning is believed to play a crucial role in neutron star "gliches" where the angular velocity of the star is quickly increased [1].

Here, I will discuss our experiments with superfluid ^{3}He immersed within a nanostructured sample consisting of parallel strands with sub-coherence-length diameter. The strands are ideal pinning sites, immobilizing quantized vortices as they are created. The set-up allows exceeding the Landau critical velocity [2], leading to increased heat capacity due to appearance of non-thermal quasiparticles, and provides a frozen view into the early times after a symmetry-breaking phase transition [3].

[1] S. Zhou, E. Gügercinoğlu *et al*, Universe **8**, 641 (2022)
[2] S. Autti, J. T. Mäkinen *et al*, Phys. Rev. Research **2**, 033013 (2020)
[3] J. Rysti, J. T. Mäkinen *et al*, Phys. Rev. Lett. **127**, 115702 (2021)

SA3.3 Transverse Sound in the Quantum Fluid States of He-3

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The quantum fluid states of He-3 host a variety of exciting collective excitations like Higgs modes as well as single particle states such surface Andreev bound states which are effectively probed using acoustic spectroscopy. In addition to longitudinal zero sound, it has been predicted that transverse zero sound can propagate at ultra low temperatures. The existence of transverse sound has been demonstrated in the superfluid but evidence for its propagation in the Fermi liquid state remains elusive. We have micro-fabricated an acoustic Fabry-Perot interferometer out of a silicon substrate to search for this transverse phonon and report no evidence for interference fringes consistent with a propagating mode. We conclude that the attenuation of transverse sound in the Fermi liquid state must be substantially higher than theoretically predicted.

SA3.4 New Heat-capacity Measurements on the Commensurate–Incommensurate Quantum Phase Transition in Submonolayer ^{3}He on ZYX Graphite

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We are conducting studies of quantum phases and phase transitions in helium (He) monolayers physisorbed on graphite substrates of much better crystallinity than Grafoil, using both synchrotron X-ray diffraction (XRD) and heat-capacity (HC) measurements. One promising target is the commensurate–incommensurate transition in submonolayer He, where the striped superheavy domain-wall (DW) structure has been predicted to exist theoretically [1] and supported experimentally by HC measurements using Grafoil [2, 3]. Our new HC data for ^{3}He indicated a much higher DW-melting peak ($C_{\rm peak}/Nk_{\rm B} = 2.5$) at 1.250 K and a much lower density ($n_{\rm peak} = 1.131$), at which the peak height shows a sharp maximum, compared to those reported previously. Here, n is the density normalized by $6.366\,{\rm nm}^{-2}$, the density of the $\sqrt{3} \times \sqrt{3}$ commensurate phase. Due to the revised $n_{\rm peak}$ value, we propose a commensurate DW structure consisting of six atomic rows, rather than the 2/5-phase [3], if it were striped one. This phase seems to coexist with an unknown uniform phase presumably with reentrant fluidity at $n \leq n_{\rm peak}$ and with the incommensurate solid phase at $n \geq n_{\rm peak}$. These new insights will soon be checked by XRD.

1. T. Halpin-Healy and M. Kardar, Phys. Rev. B **34**, 318 (1986).
2. S. V. Hering, S. W. Van Sciver, and O. E. Vilches, J. Low Temp. Phys. **25**, 793 (1976).
3. D. S. Greywall, Phys. Rev. B **47**, 309 (1993).

SA3.5 Parylene-bonded micro-fluidic channels for cryogenic experiments at superfluid He-4 temperatures

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Micro-fluidic channels have already proven their importance in the dynamical research of both classical and quantum fluids [1,2,3]. For later, the necessity of operation at low temperatures can lead to nontrivial requirements for the manufacturing process. We present flow experiments in superfluid 4He employing a custom (24.5 ×100) μm^2-sized on-chip channel. Our work proves the suitability of chip-to-chip bonding using a thin layer of Parylene-C for cryogenic temperatures as a simpler alternative to other techniques, such as anodic bonding. This technique allows the rapid production of micro-fluidic devices and is compatible with metallic electrodes on bonded surfaces. Furthermore, our approach can lead to the development of various on-chip devices, such as micro-fluidic valves or controllable impedances for use in superfluid circuits. In our experiments, a monocrystalline Si chip, bonded to a Pyrex glass top, embeds the etched meander-shaped micro-fluidic channel and a deposited platinum heater. We demonstrate that powering an on-chip platinum heater can affect the superfluid flow rate by local overheating of a section of the micro-fluidic channel.

1. A.-G. Niculescu, C. Chircov, A. C. Birca, A. M. Grumezescu, Int.J.Mol.Sci. 22(4):2011 (2021).
2. Y. Sato, R. Packard, Rep.Prog.Phys. 75, 016401 (2012).
3. E. Varga, V. Vadakkumbatt, A.J. Shook, P.H. Kim, J.P. Davis, Phys.Rev.Lett. 125, 025301 (2020).

4.6 Poster Presentations: Saturday 27th July

SA4.1 Modelling flow of superfluid ^{4}He past a rough solid wall in the $T = 0$ limit

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We present a numerical study, using the vortex filament model, of vortex tangles in a flow of pure superfluid ^{4}He in the $T = 0$ limit through a channel. The flat channel walls are assumed to be microscopically rough such that vortices terminating at the walls are permanently pinned; vortices are liberated from their pinned ends exclusively through self-reconnection with their images. In this model, the effective length scale of wall roughness δ is set by the numerical resolution which was kept constant at $\delta = 2 \times 10^{-1}$ cm while several values of channel width D were modelled.
For channels with $D = 1$ mm, 0.5 mm and 0.25 mm, sustained tangles were observed, for a period of 80 s, above the critical velocity $V_c \approx 0.18\,\mathrm{cm\,s^{-1}}$, $0.25\,\mathrm{cm\,s^{-1}}$, and $0.40\,\mathrm{cm\,s^{-1}}$, respectively. For all D, the friction force had a common dependence on flow velocity V, with the critical velocity for the onset of friction of $\approx 0.16\,\mathrm{cm\,s^{-1}}$. The stretching rate profiles indicate that the vortex line growth occurs fastest in the near-wall regions. The bulk reconnection rate followed the 3/2-power law with the total vortex line density in all channels. For the $D = 1$ mm channel, the coarse-grained velocity profile was akin to a classical parabolic profile of the laminar Poiseuille flow, albeit with a nonzero slip velocity at the walls $V_s \approx 0.2\,\mathrm{cm\,s^{-1}}$. This quasi-laminar flow with a static polarization of the vortex tangle could be characterized by the effective kinematic viscosity for the momentum transfer of $\nu_m \sim 0.1\kappa$ and effective Reynolds number $\mathcal{R}e = D(V - V_s)/\nu_m < 200$.

SA4.2 Ultralow-Temperature Susceptibility and Phase Diagram of $TmVO_4$ Proximate to Quantum Critical Point

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Nematic quantum criticality has become a hot topic in the recent condensed matter physics research because of its close association with the underlying mechanism of Fe-based superconductors and cuprate superconductors. Here we report an AC susceptibility experimental study on $TmVO_4$, which goes through a ferroquadrupolar ordering of the localized *f* electrons at low temperature. The sample crystal is immersed in liquid ^{3}He to ensure effective thermalization. By tuning transverse magnetic fields and temperatures, the H-T phase diagram near the quantum critical point is established down to the ultra-low temperature regime. The experimental results cast light on the extent of the nematic quantum fluctuations and the validity of the mean field model.

This work was supported by the Air Force Office of Scientific Research under award number FA9550-20-1-0252. Data at Stanford were obtained using a cryostat acquired with award FA9550-22-1-0084.
Part of the work was done at the National High Magnetic Field Laboratory (NHMFL or MagLab), which is supported by the National Science Foundation (NSF) through cooperative agreements DMR-2128556, and the State of Florida.

SA4.3 Pair Annihilation and Textural Transition of $\hat{d}$-soliton Lattice in ^{3}He-A

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Textural solitons in superfluid ^{3}He were observed by Gould *et al.* after applying a large tipping angle NMR excitation pulse to bulk superfluid ^{3}He-A[1]. They observed the appearance of a large satellite signal and the time evolution of the spectrum. Following those observations, Maki and coworkers proposed the textural $\hat{d}$-soliton and its variations to understand the observed phenomena[2]. The naive understanding is that the observed signal originates from a cluster of a large number of solitons (soliton lattice) rather than from several isolated single solitons. Recently, we have succeeded in generating the soliton lattice in a single slab of ^{3}He-A, where we imaged various kinds of textural walls, including the $\hat{d}$-soliton lattice. Thanks to our spatial resolution in MRI measurement, we could observe the pair annihilation of $\hat{d}$-solitons in real-time scale, while the generated soliton lattice decayed. Textural transition was also observed as time went by and the soliton lattice density decayed. We would like to present the real-time movie of those textural time evolutions.

1. C. M. Gould and D. M. Lee, Phys. Rev. Lett. **37**, 1223 (1976); C. M. Gould, T. J. Bartolac and H. M. Bozler, J. Low Temp. Phys. **39**, 291 (1980).
2. R. Bruinsma and K. Maki, Phys. Rev. B **20**, 984 (1979).

SA4.4 Broad Central Line Observed in ESR Experiments on Hydrogen Atom Isotopes in Solid Molecular Films of Hydrogen Isotopes

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We report on studies of hydrogen and tritium atoms embedded in solid molecular films of hydrogen isotopes (H_2 and T_2) at a temperature of 0.1 K and in a high magnetic field B=4.6 T by the electron-spin resonance (ESR) method. Simultaneously with the registration of the H and T atom doublets we observed a broad central line (BCL) in the ESR spectra. We studied the behavior of the BCL during warming the sample cell (SC) from 0.1 K to 300 K. It was found that the BCL remains unchanged after the disappearance of the signals from H and T atoms, and evaporating the molecular hydrogen films. The BCL was reduced after heating the SC to T=150 K, and completely disappeared after heating the SC to room temperature. We suggest that the BCL may be associated with H atoms adsorbed on the metal (Au and Pd) surfaces of the ESR resonator mirrors. H atoms on metal surfaces can be stabilized at small distances and survive at rather high temperatures.[1,2] H atoms adsorbed on the surfaces are expected to form H-H atom dimers with a strong exchange interaction resulting in the appearance of the broad line at the center of ESR spectra with a g-factor close to that of free electrons.

SA4.5 Tunable Superconducting Microwave Resonator with Liquid Helium

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A superconducting microwave resonator is an important tool with which one can interface experiments in quantum regimes such as qubits, (nano)mechanics, electrons on helium, and etc.[1] The ability to tune or detune between the microwave resonators and the intrinsic energy levels of quantum systems at will is quite useful in many cases. Magnetic flux or current has been the primary knob to change Josephson or kinetic inductance of an on-chip microwave resonators, and recently there have been reports of utilizing gate voltage to tune these resonators.[2] However, most of these techniques rely on affecting the superconductivity itself and thus deterioration of the quality factor of the resonators upon tuning the resonant frequency. Here, we present a frequency tunable superconducting microwave resonator with voltage without such degradation. The idea is to tune the capacitance of an interdigitated capacitor which makes up a part of an LC resonator with liquid helium. This technique enables in-situ tuning of an on-chip microwave resonator with applied voltage and thus will offer wide range of applications.

1. Koolstra, G., Yang, G. and Schuster, D.I.. Nat Commun 10(1), 5323 (2019).
2. Younghun Ryu, Jinhoon Jeong, Junho Suh, Jihwan Kim, Hyoungsoon Choi and Jinwoong Cha. Nano Lett. 24(4), 1223-1230 (2024).

SA4.6 Enhanced Luminescence of Oxygen Atoms in Solid Molecular Nitrogen Nanoclusters

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We observed a significant oxygen β-group luminescence enhancement during molecular nitrogen nanoclusters formation as helium gas jets with 625-5000 ppm nitrogen and 1-10 ppm oxygen impurities injected into a dense cold helium gas atmosphere. In the experiment, jets with high atomic particle concentrations - obtained by passing the abovementioned gas mixtures through an RF cavity - were injected into a beaker filled with superfluid helium at a temperature of $\approx$ 1.5 K. As the jet enters the beaker, atoms are rapidly cooled, which leads to molecular nitrogen nanocluster formations. Nanoclusters in bulk superfluid helium contain high concentrations of stabilized nitrogen atoms, accompanied by intense N atom α-group emission. As the superfluid helium evaporates and the temperature in the beaker increases above liquid helium temperatures, we observed a drastic change in the luminescence spectra. At this moment, the luminescence spectra become dominated by the β-group emission of oxygen atoms, whereas the α-group emission of nitrogen atoms is substantially reduced. At high temperatures, most of the nitrogen atoms recombine on the surface of the nanoclusters, forming excited nitrogen molecules and reducing the concentration of stabilized nitrogen atoms. The β-group emission enhancement can be explained by the effective energy transfer from excited nitrogen molecules to the oxygen atom stabilized inside N_2 nanoclusters. The observed phenomenon opens up an opportunity to detect trace amounts of oxygen contamination in gases and provides a new approach for detecting other contaminants.

SA4.7 Pressure induced surface p-wave superconductivity and higher-order topology in $MoTe_2$

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$MoTe_2$, a renowned transition-metal dichalcogenide (TMDC), presents a unique opportunity to explore topological and superconducting properties during the structural phase transition from the orthorhombic T_d Weyl semimetal phase to the monoclinic 1T' phase, which hosts higher-order topology. However, evidence of their topological properties and superconductivity under high pressure remains limited. In this presentation, we investigate the superconductivity of $MoTe_2$ and the resultant higher-order topology during the pressure-induced structural transition from the T_d to 1T' phases. We employ surface-sensitive soft-point contact Andreev reflection (PCAR) spectroscopy across various temperatures. In the T_d phase, PCAR spectra under a magnetic field reveal two-gap features with two-step patterns, indicating multi-gap superconductivity consistent with the suggested Weyl superconductivity arising from Weyl fermions. In the pressure-induced 1T' phase, the measured PCAR spectra indicate surface superconductivity, with a bulk-to-surface proximity effect inducing p-wave pairing, implying the higher-order topological nature of the normal phase.

SA4.8 Investigating Sub-Coherence Length Confinement in Superfluid ^{3}He using Nanofluidic Helmholtz Resonators

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Superfluid ^{3}He under strong confinement has attracted significant interest due to observation of novel phases not observed in the bulk.[1,2,3] The interactions with confining surfaces cause pair-breaking and alter the free energy landscape of possible phases. We have studied the effects of confinement on superfluid phases of ^{3}He using nanofluidic Helmholtz resoantors, including phase diagrams[3] and critical velocities in the A-phase.[4] The next generation of Helmholtz resonators has been fabricated to provide sub-coherence length confinement in superfluid ^{3}He. These fourth-sound resonators consist of two basins connected by a tightly confined channel and will be immersed in superfluid ^{3}He.[5] They will provide insights into phase diagrams in sub-coherence length confinements where the traditional Ginzburg-Landau theory becomes inadequate.

1. J.I.A. Li, A.M. Zimmerman, J. Pollanen, C.A. Collett and W.P. Halperin, Phys. Rev. Lett. 114, 105302 (2015).
2. L.V. Levitin, B. Yager, L. Sumner, B. Cowan, A.J. Casey, J. Saunders, N. Zhelev, R.G. Bennett and J.M. Parpia, Phys. Rev. Lett. 122, 085301 (2019).
3. A.J. Shook, V. Vadakkumbatt, P. Senarath Yapa, C. Doolin, R. Boyack, P.H. Kim, G.G. Popowich, F. Souris, H. Christani, J. Maciejko and J.P. Davis, Phys. Rev. Lett. 124, 015301 (2020).
4. A.J. Shook, E. Varga, I. Boettcher and J.P. Davis, Phys. Rev. Lett. 132, 156001 (2024).
5. E. Varga, C. Undershute and J.P. Davis, Phys. Rev. Lett. 129, 145301 (2022).

SA4.9 Ultrafast Dynamics and Control of Rotons in Superfluid Helium

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We developed a method of studying roton pairs in superfluid helium by exciting them with either a femtosecond laser pulse or a shaped laser pulse known as an optical centrifuge. By tracking the non-equilibrium dynamics of the laser-induced two-roton states on a picosecond timescale, we observe an ultrafast cooling of hot roton pairs as they thermalize with the colder gas of other quasiparticles.[1] We show that the thermalization rate increases with increasing temperature of the helium bath, with no detectable dynamics above the superfluid transition.

By implementing ultrafast coherent time- and frequency-resolved Raman scattering from roton pairs, we also demonstrate that their angular momentum can be controlled with an optical centrifuge. We show that the sign of the Raman shift, and hence the orientation of the angular momentum transferred from the laser field to the rotons, is dictated by the direction of the centrifuge rotation.[2] The observed decay of the coherent Raman signal suggests that the decoherence is governed by the scattering on thermal rotons and phonons.

1. Milner A. A., Stamp P. C. E., Milner V. (2023), "Ultrafast non-equilibrium dynamics of rotons in superfluid helium", PNAS, 120, e2303231120.
2. Milner A. A., Milner V. (2023), "Controlled excitation of rotons in superfluid helium with an optical centrifuge", Phys. Rev. Lett., 131, 166001.

SA4.10 Experimental setup for study of surface states in ^{3}He

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Nanofluidic Helmholtz resonators are enabling new ways to probe superflow of ^{3}He in strong and well-defined confinement.[1] In particular, Helmholtz resonators allow measurement of the confined superfluid fraction [2] and can be used to study dissipation mechanisms and defects.[3] Of particular interest is the study of surface states of ^{3}He, which have garnered interest for their unusual energy spectra.[4] Theoretical predictions have been made for the signatures of these surface states in the superfluid fraction under specular boundary conditions, which can be established by pre-plating our setup with a few atomic layers ^{4}He. We present the work that is being done to bring our system to a level required to begin investigating such signatures of surface states.

1. X. Rojas and J.P. Davis, *Superfluid Nanomechanical Resonator for Quantum Nanofluidics*, Phys. Rev. B **91**, 024503 (2015).
2. A. J. Shook, V. Vadakkumbatt, P. Senarath Yapa, C. Doolin, R. Boyack, P. H. Kim, G. G. Popowich, F. Souris, H. Christani, J. Maciejko, and J. P. Davis, *Stabilized Pair Density Wave via Nanoscale Confinement of Superfluid* ^{3}He, Phys. Rev. Lett. **124**, 015301 (2020).
3. A. J. Shook, E. Varga, I. Boettcher, and J. P. Davis, *Surface State Dissipation in Confined* ^{3}He$-A$, Phys. Rev. Lett. **132**, 156001 (2024).
4. H. Wu and J. A. Sauls, *Majorana excitations, spin and mass currents on the surface of topological superfluid* ^{3}*He-B*, Phys. Rev. B **88**, 184506 (2013).

SA4.11 Angular Dependence of Andreev Reflection at the Surface of Superfluid Helium-three B Phase

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Superfluid ^{3}He B phase provides an ideal platform for research of a topological matter. On the free surface, topological aspects appear such as the gap suppression. One of the previous experiments revealing surface states has been conducted to directly observe the quantum Andreev reflection (QAR)[1]. In that study, the quasi-particles (quasi-holes) were excited by an inner heater and ejected toward the liquid surface (angle of incidence : 20°), by using a black body radiator (BBR) type equipment in the superfluid ^{3}He. They measured the extra temperature rise because of the unusual characteristics of QAR that the quasi-holes (quasi-particles) go back to the BBR on the same path.
On the other hand, a theoretical result[2] shows the angle and energy dependence of QAR rate based on the spatial change of the order parameter near the surface, and that the quasiparticles with larger incident angles and smaller energies tend to have a higher proportion of QAR other than normal reflection.
In this study, we plan to measure the QAR rate over various angles and energies. Our BBR is rotated by a flexible bellows driven by the pressure of ^{4}He. The excited quasi-particles beam intensity from the BBR can be calculated by the molecular flow Monte Carlo simulation, and can be directly compared with the experimental results and theoretical value of the QAR rate.
In this presentation, we report the preliminary result.

1. T. Okuda, H. Ikegami, H. Akimoto, and H. Ishimoto, Phys. Rev. Lett. **80**, 2857 (1998).
2. Y. Nagato, M. Yamamoto, and K. Nagai, J. Low Temp. Phys. **110**, 1135 (1998).

SA4.12 Novel Oscillation Modes of Pendant Droplets of Superfluid ^{4}He

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The oscillation behavior of pendant droplets of superfluid ^{4}He suspended from a semi-spherical bottom surface of a container was captured by a high-speed camera, while superfluid ^{4}He flowed into the droplet via film flow. The oscillation was triggered by the recoil after the pinch-off and the remaining pendant droplet started to oscillate at high amplitude with negligible damping until the next pinch-off. The oscillation occurred in the whole body of the droplets with the droplet edge moving cooperatively, which can only be realized in a superfluid. The most anomalous thing about this oscillation was the size-independent oscillation period, which was quite different from the classical fluids with a size dependence. The effect of droplet edge motion was examined by altering the bottom shape to a narrow cylinder with a flat bottom, with the droplet edge pinned by the corner of the cylinder. The oscillation period in this case was dependent on the droplet size and not anomalous. The free motion of the droplet edge was shown to play a crucial role in the anomalous oscillation. When a wider cylinder was used than the natural droplet size, a different type of droplet motion was observed. The droplet moved horizontally and bounced off the cylinder's corner while suspended; it moved back and forth on the flat bottom of the cylinder. This motion can be regarded as the Noether mode, which reflects the translational symmetry of the system. Although the Noether mode was theoretically expected as the zero-frequency mode of the droplet, it has never been observed in classical fluids whose droplet edge experiences strong pinning. The free motion of the droplet edge in the superfluid leads to the occurrence of novel modes of the pendant droplets.

SA4.13 Novel experimental platform to realized one-dimensional quantum fluids

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Templated porous materials, such as MCM-41, due to uniformity of their one-dimensional structure and scalability in synthesis, have been emerging as an attractive medium for studying one-dimensional quantum fluids. However, experimental constraints of synthesizing these materials with pore radii smaller than 15 A hinders the realization of a one-dimensional quantum liquid of helium within such systems, due to smaller coherence length of helium compared to the pore radius. In this study, we present a novel approach to circumvent this limitation by preplating MCM-41 pores with cesium (Cs) metal. The nonwetting nature of helium on a Cs-coated surface, coupled with the large atomic radius of cesium, creates an optimal environment for confining a quantum liquid of helium in onedimensional geometry. Nitrogen adsorption and desorption isotherms reveal a reduction in pore radius upon preplating MCM-41 with Cs, demonstrating promising prospects for facilitating the realization of one-dimensional quantum fluids in templated porous materials.

This research is supported by the Department of Energy (DOE) .

SA4.14 Transverse sound in the Fermi liquid of ^{3}He in a 5μm microfabricated cavity

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In 1954, Landau predicted that strong interactions in the Fermi liquid can support the propagation of transverse sound in the collisionless regime, i.e., transverse zero sound (TZS). Liquid He-3, which becomes a degenerate Fermi liquid below 100 mK, satisfies the condition where TZS can exist. However, previous experiments failed to detect the TZS since the speed of TZS is close to the Fermi velocity of incoherent quasiparticles. In this poster, we summarize our interference cavity experiment to detect TZS, including the fabrication of the cavity. Our experiment implies that the attenuation of TZS should be higher than 2000cm^{-1}. We compared our data with a numerical simulation based on the theory of Kuorelahti and Thuneberg.

SA4.15 Scattering-Induced Fluidic Hall Effect in Chiral ^{3}He-A

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I report new theoretical results for the mass analogue of the Hall effect in the chiral A-phase of ^{3}He, stabilised in superfluid ^{3}He infused in uniaxially stretched silica aerogels. When mass flow of superfluid is set up in a channel containing ^{3}He-A-aerogel with chiral axis normal to the flow field, a mass current is induced in the channel transverse to both the flow direction and the chiral axis, originating from branch conversion scattering of Bogoliubov quasiparticles by the chiral superfluid order parameter due to potential scattering from disorder, realised by the silica aerogel. A chiral A-like phase is also stabilised when ^{3}He is confined to a slab of thickness comparable to the superfluid coherence length, with chiral axis aligned perpendicular to the slab surface. In this case, scattering of quasiparticles by the surface breaks chiral Cooper pairs and generates a sub-gap density of quasiparticle states. In the presence of an in-plane flow field, this surface scattering conspires with the chiral order parameter to generate skew scattering of quasiparticles giving rise to a mass current transverse to the flow field in the plane of the slab. This scattering mechanism in both ^{3}He-A-aerogel and ^{3}He-A slab leads to anomalous thermal Hall transport for nonequilibrium quasiparticles driven by a thermal gradient [1,2]. It is the origin of the fluidic analogue of the Hall effect in the presence of superflow reported here, providing an important signature of broken time-reversal and mirror symmetries of the underlying order parameter in the chiral A-phase.

1. Priya Sharma, J. A. Sauls, *J. Low. Temp. Phys.* **208**, 341(2022)
2. Priya Sharma, Anton B. Vorontsov, J. A. Sauls, *JPS Conf. Proc.* **38**, 011002 (2023)

SA4.16 Topological and magnetic properties of the interacting Bernevig-Hughes-Zhang model

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We explore the effects of electronic correlations on the Bernevig-Hughes-Zhang model via the real-space density matrix renormalization group (DMRG) method. Our study introduces a novel method to probe topological phase transitions in systems with strong correlations using DMRG, substantiated by an unsupervised machine learning methodology that analyzes the orbital structure of the real-space edges. By incorporating the full multi-orbital Hubbard interaction term, we construct a phase diagram as a function of a gap parameter (m) and the Hubbard interaction strength (U) via exact DMRG simulations on $N \times 4$ cylinders. Our analysis confirms that the topological phase persists in the presence of interactions, consistent with previous studies, but it also reveals an intriguing phase transition from a paramagnetic to a stripey antiferromagnetic topological insulator[1]. The combination of the magnetic structure factor, strength of magnetic moments, and the orbitally resolved density, provides real-space information on both topology and magnetism in a strongly correlated system.

1. Soni, R., Radhakrishnan, H., Rosenow, B., Alvarez, G., & Del Maestro, A. (2023). "Topological and magnetic properties of the interacting Bernevig-Hughes-Zhang model". arXiv:2310.17614.
**Supported by U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Award No. DE-SC0022311.

SA4.17 Andreev reflection rate on boundary of superfluid ^{3}He-B

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We have analytically obtained the Andreev reflection rate at specular boundaries of the superfluid ^{3}He-B. The Andreev equation has analytical solutions of the quasiparticle wave function under a realistic model order parameter. The order parameter of ^{3}He-B with a boundary has two components with parallel momentum and perpendicular momentum to the boundary. We consider the model order parameter with the uniform parallel component and the modulating perpendicular component. The perpendicular component is suppressed near the boundary as the hyperbolic tangent function with the coherence length scale. The analytically obtained wave function provides the result that the Andreev reflection is absent at the free surface for quasiparticles with energy above the superfluid gap.[1] We discuss the difference in the Andreev reflection rate between the results calculated by using the model order parameter and the self-consistent order parameter.[2] In the presentation, the Andreev reflection rate at the interface of the superfluid ^{3}He-B and the normal ^{3}He will be also reported. We will discuss the scattering of quasiparticles emitted in the normal ^{3}He on the Majorana bound state at the interface.

1. Y. Tsutsumi, H. Ikegami, and K. Kono, J. Low Temp. Phys. (2024).
2. Y. Nagato, M. Yamamoto, and K. Nagai, J. Low Temp. Phys. **100**, 1135 (1998).

SA4.18 Topological Hall Effects in Magnetic Metals with Chiral Spin Textures

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We derive a Boltzmann transport equation for conduction electron transport in magnetic metals with chiral spin textures (skyrmions) starting from the Keldysh formulation of Dyson's equation for metals with an *s-d* exchange interaction. We show that the anomalous electrical and thermal Hall effects, electric polarizations induced by the electric field and temperature gradient, and conductivity due to the steady-state motion of skyrmions depend on the *scalar spin chirality*,[1] $\mathbf{S}\cdot(\partial_{r_i}\mathbf{S}\times\partial_{r_j}\mathbf{S})$. and spatial average of these transport coefficients are proportional to the net topological charge.[2] In addition, we find that the spin Hall effect, spin Nernst effect, Edelstein effect, and temperature-gradient-induced magnetization are determined by the *vector spin chirality*, $\mathbf{S}\times\partial_{r_i}\mathbf{S}$ and $\partial_{r_i}\mathbf{S}\times\partial_{r_j}\mathbf{S}$.[1] Finally, we show that conduction electron scattering off moving skyrmions leads to violaiton of the Wiedemann-Franz law.

1. Nagaosa, N., "Anomalous Hall Effect - A New Perspective", J. Phys. Soc. Japan, 75, 042001 (2006).
2. Volovik, G. E., "Linear momentum in ferromagnets". J. Phys. C: Solid State Phys. 20, L83 (1987).

SA4.19 Failed superconductivity in chemically-substituted Mott spin liquid materials

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The quasi-2D Mott organic materials are often considered as the simplest model system for the study of strongly correlated physics in the absence of magnetic order. We explore the superconductivity of κ-[(BEDT-TTF)$_{1-x}$(BEDT-STF)$_x$]$_2$Cu$_2$(CN)$_3$ for $x \sim 0.11$, i.e. in the phase coexistence region between the Mott insulator and the Fermi liquid phases, by measuring dc transport in perpendicular magnetic fields H up to 18 T and temperatures T down to 20 mK. Despite the presence of the superconducting fluctuations,[1] at $H = 0$ the resistivity saturates at a finite value or shows an upturn as $T \to 0$. We extract the intrinsic resistivity and the volume fraction of the superconducting domains based on the percolation theory,[2] and successfully perform a scaling analysis for the corresponding superconducting transition. The critical exponent $\nu z \sim 1.3$, in good agreement with the values established in thin films of conventional superconductors.[3] Our results reveal that this "failed superconductor" behavior arises due to the intrinsic inhomogeneities characteristic of the phase coexistence region. *Supported by NSF DMR-2104193, DMR-1707785, and NHMFL via DMR-2128556, DMR-1644779 and the State of Florida.

1. Saito, Y., Löhle, A., Kawamoto, A., Pustogow, A., M Dressel, M., Crystals **11**, 817 (2021).
2. Kirkpatrick, S., Rev. Mod. Phys. **45**, 574 (1973).
3. Yazdani, A., Kapitulnik, A., Phys. Rev. Lett. **74**, 3037 (1995).

SA4.20 Structure of Molecular Nitrogen Nanoclusters Containing Stabilized Nitrogen Atoms

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Impurity-helium condensates (IHCs) formed by injecting the discharge products of gaseous mixtures of helium atoms and nitrogen molecules into bulk superfluid ^{4}He at temperature 1.5K, were studied by X-band electron spin resonance (ESR). IHCs consists of collections of N_2 nanoclusters which form aerogel-like structure inside bulk HeII. It was found that N_2 nanoclusters have a two shell structure, an outer shell which contains high concentration of stabilized N atoms and an interior shell with lower concentrations of N atoms. In this paper we have studied the dependence of the shell structure of the N_2 nanoclusters on the N_2/He ratio in the condensed gas mixtures from 0.06% to 1%. The highest local concentration of N atoms in nanoclusters ($1.2 \cdot 10^{21}$cm^{-3}) was observed in the sample prepared from the gas mixture containing the lowest nitrogen admixture (0.06%). Additionally, the evolution of nanocluster structures were studied as the samples were drained of liquid helium (T$\leq$ 3.5K) and warmed beyond the point of explosive recombination (3.5K $\leq$ T $\leq$ 6.5K).

SA4.21 Simulating quasiparticle exchange with a 2D boundary superfluid

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Previous experiments in superfluid ^{3}He have demonstrated that surface-bound states contribute to heat transport in the system at low temperatures [1,2]. Our recent experiments investigated the flow of heat between two bulk volumes, a small box within a larger experimental cell, connected by a small orifice. When we position a thin wall close to the hole outside the box the direct line of sight for bulk quasiparticle transport is impeded. Our measurements show that bulk transport alone cannot be responsible for the heat flow between the two volumes, and we argue that transport facilitated by the surface states in the superfluid must be responsible for the experimental observations. We have constructed a simulation of ballistic quasiparticle transport in this geometry. Further calculations to reproduce the experimental measurements and more detailed analysis of the experimental data will allow characterising the surface transport and its coupling to the bulk quasiparticle gas.

1. S. Autti *et al*, Nature Communications **14**, 6819 (2023)
2. S. Autti *et al*, Nature Communications **11**, 4742 (2020)

SA4.22 Numerical study on Kelvin waves excited by a vibrating nanobeam in superfluid helium-4

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Kelvin waves on a quantized vortex are important as an elementary process of quantum turbulence at small length scales below the inter-vortex distance ℓ. Recently, a real-time nanoscale detection of quantized vortices at millikelvin temperatures has been achieved by using a vibrating nanobeam [1]. As a future work, this experimental method [1] can also investigate the dynamics of Kelvin waves on the captive vortex, where a vibrating nanobeam excites Kelvin waves. To provide theoretical insight, we numerically consider Kelvin waves excited by a vibrating nanobeam. The conditions for resonant Kelvin waves are analyzed using the dispersion relation, and the frequency $f = 1.00$ MHz is found to be for $n = 7$ mode. We have performed simulations of a single vortex filament bridging between two parallel plates by using the vortex filament model at 0 K [2]. The upper plate corresponds to the rough surface of a nanobeam, and the attached point of the filament is externally oscillated. Near the upper surface, the oscillatory superflow is also applied, because the beam oscillation can induce the flow around it. The simulation results confirmed that the Kelvin waves of $n = 7$ mode are well excited. We further simulated Kelvin waves at various frequencies around $f = 1.00$ MHz to analyze the resonance profile.

[1] A. Guthrie et al., "Nanoscale real-time detection of quantum vortices at millikelvin temperatures", Nat. Commun. **12**, 2645 (2021). [2] T. Nakagawa et al., "Dynamics of pinned quantized vortices in superfluid ^{4}He in a microelectromechanical oscillator", Phys. Rev. B **108**, 144110 (2023).

SA4.23 Polarized filaments and decay of quantum turbulence coupled with normal-fluid turbulence in superfluid helium-4

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Quantum turbulence can have analogies to classical turbulence, and this type of turbulence is called Quasi-Classical Turbulence (QCT). The decay of QCT obeys the power law $L \propto t^{-3/2}$ with the vortex line density L [1]. It is believed that, on large length scales, the two fluids tend to move together due to the mutual frictions and can behave like a classical fluid [2]. Here, we study QCT by using the coupled simulation for quantum turbulence and normal-fluid turbulence at 1.9 K [3]. First, statistically steady states are simulated to analyze the locally poralized structure of filaments. Here, the normal fluid is made turbulent by external forces. The calculation is accelerated by the fast multipole method. It is found that, in coflow, vortex bundles are formed by the mutual frictions of the normal-fluid turbulence. On the other hand, the bundle formation is suppressed in counterflow. Second, the decay of quantum turbulence is simulated by stopping the external forces. Our coupled simulations obtained the power law $L \propto t^{-3/2}$ for the decay from coflow turbulence, while the one-way simulation showed the power law $L \propto t^{-1}$. This implies that the QCT power law $L \propto t^{-3/2}$ requires that the two turbulences decay together.

[1] S. R. Stalp et al., Phys. Rev. Lett. **82**, 4831 (1999). [2] W. F. Vinen, Phys. Rev. B **61**, 1410 (2000). [3] S. Yui et al., Phys. Rev. Lett. **129**, 025301 (2022).

4.7 Oral Presentations: Monday 29th July

MO1.1 Signature of electronic phase transitions in multielectron bubbles

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Multielectron bubbles (MEBs) are charged cavities in liquid helium that provide a rich platform to study the behavior of electrons on curved surfaces, and to investigate properties of two-dimensional electron layers at unexplored densities. We will discuss our recent results pertaining to the stability and dynamics of the MEBs in liquid He4 and liquid He-3 across a wide temperature range. We present experimental evidence of phase transitions and novel quantum effects of the electron layer within the MEBs.

MO1.2 Rotational Control of Helium Dimers in Superfluid Helium

V. Milner, A. A. Milner, I. MacPhail-Bartley, K. Preocanin, S. Dasgupta, and X. Peng

Department of Physics & Astronomy, University of British Columbia, Vancouver, Canada

I will discuss our recent results on coherent excitation and coherent control of metastable helium dimers (He_2^*) inside bulk superfluid helium by means of shaped ultrashort laser pulses. I will present an experimental study of the laser-induced rotation of helium dimers inside the superfluid ^{4}He bath at variable temperature. The coherent rotational dynamics of He_2^* is initiated in a controlled way by ultrashort laser pulses, and tracked by means of time-resolved laser-induced fluorescence. We detect the decay of rotational coherence on the nanosecond timescale and investigate the effects of temperature on the decoherence rate. The observed temperature dependence suggests a non-equilibrium evolution of the quantum bath, accompanied by the emission of the wave of second sound.[1]

I will also report on the experimental demonstration of the rotational control of helium dimers by a periodic sequence of linearly polarized femtosecond pulses (a pulse train). We show that the degree of rotational excitation of He_2^* can be enhanced or suppressed by varying the period of the pulse train, whereas the directionality of molecular rotation can be controlled by the relative angle between the polarization vectors of pulses in the train.[2]

1. Milner A. A., V. A. Apkarian, Milner V. (2023), “Dynamics of molecular rotors in bulk superfluid helium”, Science Advances, 9, eadi2455.

2. Milner A. A., MacPhail-Bartley I., Preocanin K., Dasgupta S., Peng X., Milner V. (2024), “Coherent control of molecular rotation in superfluid helium”, Phys. Rev. A, 109, 013110.

MO1.3 SIGNATURES OF EXCITON CONDENSATION IN Si/SiGe BILAYERS

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Two-dimensional semiconducting electron gasses in the quantum Hall regime are a rich platform for the study of the condensation of spatially separated excitons. Here, we report on the fabrication and the observation of signatures of an excitonic state in a novel heterostructure, an asymmetric undoped Si/SiGe bilayer. Through a combination of top and bottom gates, this novel device architecture enables independent tuning of the electron density in both layers while allowing for the realization of independent contacts to each quantum well. The experimental observation of a quantum Hall state at $\nu_{total} = 1$ signals the existence of an interlayer coherent state, either through wave-function hybridization or through the Bose-Einstein condensation of excitons. We report on the evolution of this interlayer coherent state as a function of tunneling strength and density imbalance, both through the evolution of the energy gap of the $\nu_{total} = 1$ and $\nu_{total} = 2$ quantum Hall states, and through measurements requiring independent contacts to each quantum well. The interplay between valley splitting and this interlayer coherence effect is also discussed.

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MO1.4 Rydberg-state detection in a small ensemble of trapped electrons

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Quantum Dynamics Unit, Okinawa Institute of Science and Technology, Japan

Recently, qubit based on electrons hovering above cryogenic noble-gas substrates challenged other technologies in the race for a fault tolerant quantum computer. In this vein, several qubit implementations have been explored. In the presented work we contribute to the development of a hybrid spin-Rydberg electron qubit above superfluid helium [1]. Specifically, we aim at detecting the Rydberg transition of a single trapped electron. In the experiment, a small ensemble of electrons is electrostatically trapped above an electrode inside a single micro-sized channel filled with superfluid helium. The ensemble is depleted by varying the confining potential, while performing the Rydberg-state spectroscopy using an image charge detection technique [2]. The evolution of the spectral lineshape upon depletion reveals a nontrivial ground state structure of the charge system, which has been analyzed with molecular dynamics simulation. Additionally, we present observation of sub-hertz oscillations of Rydberg frequency caused by fluctuation of the helium film thickness due to the thermo-acoustic oscillations. Thanks to extreme sensitivity of the Rydberg resonance to the film thickness, we were able to estimate a level of the film-thickness fluctuations, which might help to clarify the nature of decoherence sources observed in other experiments with electron qubits on cryogenic substrates.

1. E. Kawakami, J. Chen, M. Benito, and D. Konstantinov. "Blueprint for quantum computing using electrons on helium". Phys. Rev. Applied 20, 054022 (2023).
2. M. Belianchikov, J. Krauss, and D. Konstantinov. "Resonant cryogenic amplifier for electron-on-helium image charge detection". J. Low Temp. Phys (2024).

MO1.5 Plasmon mode engineering and cQED with electrons on helium

Camille A. Mikolas[a], N. R. Beysengulov[b], A. J. Schleusner[a], D. G. Rees[b], and J. Pollanen[a]

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An ensemble of electrons trapped above a superfluid helium surface (eHe) is a paradigm system for investigating and controlling the collective charge dynamics of low-dimensional electronic matter. Of particular interest is the ability to engineer the spatial and spectral structure of surface plasmon modes in this system for integration into hybrid quantum systems or circuit quantum electrodynamic device architectures. We present experiments on an eHe microchannel device designed to host microwave-frequency plasmon modes with a spatial structure dictated by the geometry of the channel confinement. Plasma oscillations are generated via local microwave frequency excitation of the microchannel confined electrons. When the plasmon mode is resonant with the excitation frequency, it produces non-equilibrium heating of the electrons, which we detect as changes in the device conductance via simultaneous transport measurements. We find the spatial structure of the surface plasmons is in good agreement with our model and device design parameters and the mode frequencies can be tuned over a broad range (several GHz) by precisely varying the electron areal density in the central channel. Furthermore, by measuring the plasmon mode linewidths and their power dependence, we quantify the level of spatial homogeneity associated with each plasmon mode. The results highlight the versatility of electrons on helium as a model system for investigating, and engineering, the collective mode structure of low-dimensional Coulomb liquid and solid states. Lastly, we present a next generation device and intial results where microchannel confined collective excitations of eHe is coupled to a superconducting coplanar waveguide resonator.

MO2.1 Phase separation in cold para-H_2 - D_2 clusters

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[c]Kyoto University, Kyoto, Japan

Low temperature phase separation in mixtures of ^{3}He and ^{4}He isotopes is a unique property of quantum fluids. Hydrogen has long been considered as another potential quantum liquid and has been predicted to be superfluid at T <1 K well below freezing temperature of about 14 K. Phase separation has also been predicted in mixtures of para-H_2 and D_2 at T <3 K. To defer the freezing, we produced clusters containing para-H_2 and mixtures of para-H_2 and D_2 at estimated temperature of about 2 K whose state was studied by vibrational Raman spectroscopy.[1−2] The results indicate that the clusters are liquid and show the phase separation of the isotopes. The phase separation is further corroborated by the quantum molecular dynamics simulation.

1. K. Kuyanov-Prozument and A. F. Vilesov (2008). "Hydrogen clusters that remained fluid at low temperature". Phys. Rev. Lett. 101, 205301.
2. R. Sliter, Kim Hyeon-Deuk, and A. F. Vilesov (2024). "Phase separation in cold para-H_2-D_2 clusters". Phys. Rev. Lett. 132, 206001.

MO2.2 Quantum Dripping of Superfluid ^{4}He

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Superfluid ^{4}He open systems have not been thoroughly studied to determine if their behavior differs significantly from classical fluids. To address this, we observed the dripping behavior of superfluid ^{4}He with a high-speed video camera which spontaneously flowed out from a cup via a film flow.[1] A superfluid pendant droplet grew on the bottom surface of the cup and eventually pinched off to fall as the superfluid flowed into the droplet. The dripping period was found to change not smoothly but stepwise and to be robustly "quantized" even at varying input flow rates. This was due to the high amplitude oscillation of the droplet caused by the superfluidity. The high amplitude oscillation determined the timing of dripping; they can drip only in the downward phase of the oscillations, and therefore, the number of oscillations strongly correlated with the dripping period, leading to the quantization. The superfluid open system self-organizes to drip at the fixed periods, breaking the time translation symmetry driven by the continuous superflow without periodical driving. A possible realization of a new kind of continuous time crystal will be discussed. While larger droplets oscillate at a longer period for classical fluids, the superfluid droplet was shown to oscillate at a size-independent period; thus, the oscillation itself was anomalous. The oscillation occurred not only in the lower part but in the whole body of the droplets, causing the droplet edge on the cup surface to move corporately. Since such free motion of the droplet edge can be realized owing to the superfluidity, the anomalous oscillation should be specific to the superfluid.

1. Nagatomo, R. *et al.* (2023). "Robust Quantization of Dripping Periods of Superfluid ^{4}He". J. Phys. Soc. Jpn. **92**, 124601.

MO2.3 Exploring Tomonaga-Luttinger liquid of the 1D ^{3}He using NMR

T. Matsushita[a], A. A. Temurjonov[a], Y. Miyauchi[a], Y. Kobayashi[a], M. Hieda[b], and N. Wada[a]

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To explore possibility of ^{3}He Tomonaga-Luttinger liquid (TLL), one-dimensional (1D) ^{3}He fluid formed in ^{4}He-precoated nanochannels of FSM a few nm in diameter have been investigated by ^{3}He nuclear magnetic resonance (NMR). At dilute ^{3}He densities (on the order of 0.01 atomic layers) where all ^{3}He occupy ground states of azimuthal motion in 1D channels at $T = 0$, the quantum-mechanically genuine 1D fluid of ^{3}He adatoms is realized at low temperatures. The experimental 1D conditions for the temperature and ^{3}He density were determined by a characteristic maximum of the heat capacity or density-independent decreases of the susceptibility. In this 1D state of ^{3}He, characteristic increases of the spin-spin relaxation time T_2 have been observed with decreasing temperature below 0.12K.[1] The increase proportional to the inverse of temperature was observed only at the genuine 1D conditions of ^{3}He, and agrees with that expected for possible TLL states. On the other hand, for evidence of the TLL behavior several issues remain, such as T_2-increases similarly observed in both degenerate and non-degenerate regions contrasting with a qualitative difference of spin-lattice relaxation T_1, and the range of ^{3}He diffusive motion in the NMR time scale compared to the 1D channel length. For direct observation of the motional state of 1D ^{3}He in nanochannels, we have recently started measurements of spin diffusion for ^{3}He. Present results will be also shown in this talk.

1. Matsushita, T. et al. (2021). "Temperature-linear spin-spin relaxation rates of one-dimensional ^{3}He fluid formed in nanochannels". Phys. Rev. B **103**, L241403 (2021).

MO2.4 Experimental realization of one dimensional helium

A. Paul E.[a], Adrian Del Maestro[b], Sutiritha Paul[b], Nathan S. Nichols[c], Timothy R. Prisk[d], Prabin Prakrith[a], and Garfield Warren[a]

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[b]Department of Physics, University of Tennessee Knoxville
[c]Argonne Leadership Computing Facility, Argonne National Laboratory
[d]Materials Science Division, Lawrence Livermore Laboratory

As the spatial dimension is lowered, locally stabilizing interactions are reduced, leading to the emergence of strongly fluctuating p hases o f m atter w ithout c lassical a nalogues. R ealizing 1 D p latforms h as been elusive, due to their inherent lack of stability, with a few notable exceptions such as spin chains and ultracold low-density gasses. The inability of such systems to exhibit long range order is essential to their universal description in terms of the Tomonaga-Luttinger liquid theory Here we report on the experimental observation of a one dimensional quantum liquid of ^{4}He using nanoengineering by confining it within a porous material preplated with a noble gas to enhance dimensional reduction. The resulting excitations of the confined ^{4} He, c onfirmed by ne utron sc attering, ar e qu alitatively di fferent tha n three and two-dimensional superfluid h elium, a nd c onsistent w ith Q uantum M onte C arlo c alculations. The results can be analyzed in terms of a mobile impurity in an otherwise linear Luttinger liquid allowing for the extraction of the microscopic parameters describing the emergent quantum liquid.

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MO2.5 The one-fluid extended model of superflui helium II: recent results

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I present our recent results on the one-fluid extended model. In particular, we perform the first numerical comparison between the two main existing models of superfluid helium: the two-fluid model proposed by Landau and the one-fluid extended model proposed from the extended thermodynamics. The numerical experiments in this paper regard the profiles of the so-called normal and superfluid components in 2D counterflow turbulence. We are also interested to study the influence of the boundary conditions of the velocity fields. To make progress, we also perform numerical simulations where we allow a slip velocity of the viscous component at the walls, and observe how this impacts on velocity fields and density profiles of distribution of quantized vortices.

MO3.1 Vortex dynamics at sub-quantum length scales, probed with a NEMS device

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[c]Department of Physics and Astronomy, The University of Manchester, UK

Recent proposals for classification of quantum turbulent states [1,2] stress different dynamics evolving at scales larger and smaller than the so-called quantum length scale comparable to the intervortex distance. As temperature approaches zero, the smaller scales, where quantization of vorticity is important, become more and more involved in the turbulent motion, with the Kelvin-wave cascade on an individual vortex being an essential part of the theoretical picture. Large-scale motion and vortex reconnections in flows involving many vortices obstruct experimental observations of relevant small-scale dynamics with macroscopic probes. To overcome this difficulty, we have developed nanomechanical oscillators that are sensitive to the force from a single quantized vortex [3]. The devices are suspended above a window and submerged in superfluid ^{4}He or ^{3}He-B. We have measured the response of these devices in both superfluids at temperatures below $0.2\,T_c$ when vortices are generated by a tuning fork or by rotation of the cryostat. The largest size of the NEMS oscillator is well below the quantum scale in the applied flow. We have observed attachment and detachment events of individual vortices, Kelvin waves on a single attached vortex, and the influence of the quantum boundary layer on vortex dynamics.

[1] L. Skrbek *et al*, Proc. Nat. Acad. Sci. **118**, e2018406118 (2021).
[2] C.F. Barenghi *et al*, AVS Quantum Science **5**, 025601 (2023).
[3] T. Kamppinen *et al*, Phys. Rev. B **107**, 014502 (2023).

MO3.2 Numerical Studies of Quantum Turbulence

M. Tsubota

Department of Physics, Osaka Metropolitan University, Japan

Quantum hydrodynamics and turbulence have been extensively studied in superfluid helium since the 1950s and in atomic Bose-Einstein condensates (BECs) since 1995. Here, I present recent significant results from numerical studies on quantum turbulence (QT) in both systems. In superfluid helium, recent groundbreaking visualization experiments have sparked further theoretical and numerical investigations into the fully-coupled dynamics of the two-fluid model.[1,2] Another noteworthy area of focus is QT in micromechanical systems.[3,4] I discuss vortex dynamics in these highly confined spaces, where pinning effects play a dominant role. Regarding QT in atomic BECs, one of the most notable advancements is the observation of statistical laws[6] and the cascade process that sustains QT[7] within a box potential. It is known that symmetry restoration is among the most intriguing characteristics of classical turbulence,[8] a phenomenon also reported in Ref. 6. We revealed that as turbulence progresses, the particle distribution in momentum space becomes isotropic,[9] and isotropy emerges in rotating turbulence.[10]

1. S. Yui, H. Kobayashi, M. Tsubota, W. Guo, Phys. Rev. Lett.124, 144301 (2020) 2. Y. Tang, W. Guo, H. Kobayashi, S. Yui, M. Tsubota, T. Kanai, Nat. Commun.14, 2941 (2023) 3. A. Guthrie et al., Nat. Commun.12, 2645 (2021) 4. C. S. Barquist et al., Phys. Rev. B101, 174513 (2020) 5. T. Nakagawa, M. Tsubota, K. Gunther, Y. Lee, Phys. Rev. B108, 144110 (2023) 6. N. Navon et al., Nature539, 72 (2016) 7. N. Navon et al., Science366, 1267 (2019) 8. U. Frisch, Turbulence: The legacy of A , N, Kolmogorov (Cambridge University Press)(1995) 9. Y. Sano, N. Navon, M. Tsubota, EPL140, 66002 (2022) 10. Y. Sano, M. Tsubota, Phys. Rev. A109, L031301(2024)

MO3.3 Transition from 2D to 3D quantum turbulence

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Turbulence in two dimensions differs significantly from the three-dimensional case due to the transfer of turbulent kinetic energy to the large scales in a process called the inverse cascade. All real flows, however, have a finite size in the third dimension. As the thickness of the thin layer flow increases, the three-dimensional forward cascade is expected to set in, and the inverse cascade is expected to be fully suppressed with different critical flow aspect ratios with both cascades present for the intermediate values [1]. We investigate this transition using nanoscale flows of superfluid ^{4}He.

We will present a systematic study of the transition to turbulence in oscillatory flow in slab geometry using superfluid helium confined to channels of ten different heights spanning 0.5 to 2 µm. Using the attenuation of the fourth sound [2], we observe the growth of the number of quantized vortices as the turbulence develops. The transition to turbulence strongly depends on the scale of confinement and the large-scale friction set by the temperature. For continuously ramped drive, we observe simple hysteretic loops in the transition to nonlinear dissipation at both ends of the studied confinement range with a complex multistable transition behavior close to 1 µm confinement. Coupled with simulations of dynamics of confined quantized vortices using the vortex filament model, we explore whether the observed change in transitional behavior is due to the switching of the dominant type of the turbulent cascade.

1. S. J. Benavides, A. Alexakis, *J. Fluid Mech.* **822**, 364 (2017)
2. F. Novotný *et al.*, *J. Low Temp. Phys.* (2024) DOI 10.1007/s10909-024-03112-2

MO3.4 Energy Emission from a Trapped Quantum Vortex in Superfluid Helium

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[b]Department of Low Temperature Physics, Charles University, Prague, Czech Republic
[c]Now at: Department of Physics, University of California, Berkeley, United States of America
[d]Now at: Centre for Quantum Technologies, National University of Singapore, Singapore.
[e]Department of Chemistry and Material Science, Weizmann Institute of Science, Israel

Topological defects manifest as quantum vortices in both superconductors and superfluid helium. Investigations of quantum vortices in superconductors are confined to the surface, while superfluid helium allows for a three-dimensional study. Our pioneering work[1] has demonstrated the trapping of a quantum vortex string on a mechanical resonator. By measuring changes in the resonance frequency, we identified three distinct states of the trapped vortex: a pristine state without any vortices, a fully trapped state where the vortex aligns entirely with the length of the oscillator, and a partially trapped state where a section of the vortex is anchored perpendicular to the oscillator.

In our current research, we've mechanical probed the partially trapped states. We observe a critical velocity indicating the onset of an additional energy dissipation mechanism, which later becomes saturated. Analysis on the energy reveals the emission of a quantized amount of energy per cycle of oscillation of the resonator. This leads us to conclude a novel mechanism for vortex line relaxation: roton emission.

1. Guthrie, A. et al. (2021). "Nanoscale real-time detection of quantum vortices at millikelvin temperatures". Nature Communications

MO3.5 Second Harmonic Generation by Dynamics of Pinned Vortex

Y. Masaki and Y. Matsubayashi

Department of Applied Physics, Tohoku University, Sendai, Japan

Recently, non-equilibrium dynamics and non-linear optical response of superconductors have been intensively studied by using terahertz radiation which energy is on the order of superconducting gaps. Nakamura *et al.* reported the giant second harmonic generation (SHG) from thin film superconductors in which transport current was applied. As an interpretation of their experimental results, they proposed the pinned vortex dynamics driven by the THz irradiation on the basis of the point particle model, but its theoretical support has not been sufficient.
We performed numerical simulation based on the time-dependent Ginzburg–Landau equation coupled with the Maxwell equations to study the photo-driven dynamics of the superconducting vortex. This framework allows us to take into account the effects of the vortex deformation as well as other contributions to the SHG origin. Our main results are mostly consistent to the experimental observation and are summarized as follows: We confirmed that application of the transport current enhances the SH component of the total current when the transport current was applied to break the inversion symmetry. The intensity of the SH component has a noticeable peak as a function of the driving frequency. The peak frequency is due to the vortex motion around the pinning potential. This is confirmed by investigating in detail the spatial structure of the SH component, and the time evolution of the center-of-mass coordinate of the vortex. We also clarified that the vortex motion around the pinning potential was involved with its deformation in contrast to the point particle model.

MO4.1 Atomic Fermi Fluids in Optical Boxes

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For the past two decades harmonically trapped ultracold atomic gases have been used with great success to study fundamental many-body physics in flexible experimental settings. However, the resulting gas density inhomogeneity in those traps makes it challenging to study paradigmatic uniform-system physics (such as critical behavior near phase transitions) or complex quantum dynamics. The realization of homogeneous quantum gases trapped in optical boxes has marked a milestone in the quantum simulation program with ultracold atoms[1]. These textbook systems have proved to be a powerful playground by simplifying the interpretation of experimental measurements, by making more direct connections to theories of the many-body problem that generally rely on the translational symmetry of the system, and by altogether enabling previously inaccessible experiments. I will present a set of studies with ultracold fermions trapped in a box of light. This platform is particularly suitable to study problems of stability and quantum dynamics. I will briefly discuss our recent studies of the stability of the spin-1/2 Fermi gas with repulsive contact interactions[2], and the three-component Fermi gas with spin-population imbalance[3]. I will show our recent observation of the quantum Joule-Thomson effect for fermions[4] and the realization of strongly driven Fermi polarons[5]. Finally, I will mention ongoing efforts on the dynamics of a strongly driven ideal Fermi gas, and the emergence of sound in a Fermi fluid with tunable interactions.

1. N. Navon, R.P. Smith, Z. Hadzibabic, Nature Phys. 17, 1334 (2021)
2. Y. Ji et al., Phys. Lev. Lett 129, 203402 (2022)
3. G.L. Schumacher et al., arXiv:2301.02237
4. Y. Ji et al., Phys. Lev. Lett 132, 153402 (2024)
5. F.J. Vivanco, arXiv:2308.05746

MO4.2 Observation of relaxation stages in out-of-equilibrium closed quantum systems: the case of turbulence in atomic trapped superfluid

M. A. Moreno Armijos, A. R. Fritsch, A. D. García-Orozco, S. Sab, L. Madeira, G. Telles, and V. S. Bagnato

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The temporal evolution of a non-equilibrium quantum system is the most crucial aspect of its dynamics. We introduce ro-translational excitations in a 87Rb Bose-Einstein condensate, which, under certain conditions, induce turbulence in the system. Once this non-equilibrium state is achieved, the system is allowed to evolve until it reaches equilibrium. Throughout this dynamical process, the characteristic particle cascade is observed, featured by the appearance of a powerlaw in the momentum distribution along with temporal windows of meta-stability showing the emergence of universal scaling. Subsequently, the system reaches a pre-thermalization stage with minimal variation, followed by a reverse cascade that forms a new condensate with fraction and temperature different f rom t he i nitial o ne. T his a llows the assessment of various physics inputs during relaxation. The system is investigated under different initial excitations and represents a closed system suitable for investigations of many phenomena. In the final stage the presence of double cascade operating simultaneously. While a reverse particle cascade populates the new BEC, energy in a direct cascade takes the energy for large momentum. Many aspects of the observations shall be discussed during the presentation. Work supported by FAPESP and CNPq.

MO4.3 Quantum Hall physics in the quantum Foucault pendulum

R. J. Fletcher

MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics, and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

When charged particles are placed in a magnetic field, the single-particle energy states form discrete, highly-degenerate Landau levels. Since all states within a Landau level have the same energy, the behaviour of the system is completely determined by the interparticle interactions and strongly-correlated behaviour such as the fractional quantum Hall effect occurs. Here, we present recent experiments from MIT on the microscopy of a rapidly-rotating Bose-Einstein condensate, in which the Coriolis force felt by a massive particle in a rotating frame plays the role of the Lorentz force felt by a charged particle in a magnetic field. In a magnetic field the X and Y coordinates of a particle do not commute, leading to a Heisenberg uncertainty relation between spatial coordinates. We exploit the ability to squeeze non-commuting variables to dynamically create a Bose-Einstein condensate occupying a single Landau gauge wavefunction, and investigate its purely interaction-driven dynamics in the lowest Landau level. We reveal a spontaneous crystallization of the fluid, driven by the interplay of interactions and the magnetic field; increasing the cloud density smoothly connects this quantum behavior to a classical Kelvin-Helmholtz-type hydrodynamic instability, driven by the sheared superfluid flow profile arising from the vector potential. Finally, we project a sharp optical boundary onto our system and demonstrate controllable injection of its associated chiral edge modes, quantifying their speed, excitation energy, and dependence upon wall structure.

MO4.4 Dynamics of Topological Defects in ^{3}He-A Films following a Quench

N. Gluscevich and J. A. Sauls

Hearne Institue of Theoretical Physics, Louisiana State University, USA

In equilibrium, confined films with thickness $D \lesssim 10\,\xi_0$ of superfluid ^{3}He-A have the chiral axis, $\vec{\ell}$, locked normal to the surface of the film. There are two degenerate ground states $\vec{\ell} \parallel \pm\hat{z}$. However, for a temperature quench, i.e. cool down through the phase transition at a finite rate, causally disconnected regions of order parameter fluctuations are expected to develop and evolve into an inhomogeneous ordered phase that hosts both domain walls between time-reversed chiral phases as well as point vortices with winding numbers $n \in \mathbb{Z}$. Simulations based on a time-dependent generalization of Ginzburg-Landau theory for strong-coupling ^{3}He reveals both types of topological defects to be present in our simulations.[1] We show simulation results for the dynamics of vortices interacting with anti-vortices as well as domain walls. We report results for the statistics of domain wall length, vortex density, and winding number and compare with other theoretical models for full counting statistics of the vortex density population. We also show that the vortex density as a function of quench rate agrees with the scaling relation predicted by Kibble[2] and Zurek[3].

1. M. Hindmarsh, J. A. Sauls, K. Zhang, QUEST-DMC group, https://arxiv.org/abs/2401.07878
2. T. W. B. Kibble, J. Phys. A 9, 1387 (1976).
3. W. H. Zurek, Nature 317, 505 (1985).

4.8 Oral Presentations: Tuesday 30th July

TU1.1 Recent Quantum Evaporation R&D towards the HeRALD Dark Matter Experiment

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University of Massachusetts, Amherst, USA

The HeRALD effort is working towards tests of sub-GeV dark matter models using a few-gram isotopically pure 4He target at T<10mK. A particle scatter within the target produces phonons and rotons, which result in the quantum evaporation that is ultimately sensed. We report on the developed a film-blocking method employing an unoxidized Cs film, and we also report on the first observations of quantum evaporation signals using our setup. A key result of this work is the measurement of the quantum evaporation channel's 'gain' (energy observed : energy deposited in 4He) of 0.15±0.012, which will enable 4He-based dark matter experiments in the near term[1].

1. TESSERACT Collaboration (2023). "Applying Superfluid Helium to Light Dark Matter Searches: Demonstration of the HeRALD Detector Concept". arXiv:2307.11877.

TU1.2 Superfluid Effective Field Theory: aspects of light dark matter detection and normal fluid viscosity

Y. You[a], W. Xue[b], J. Smolinsky[b], K.T. Matchev[b], K. Gunther[b], Y. Lee[b], T. Saab[b], and B. Xu[c]

[a]DC Campus, Bard Early Colleges, USA
[b]Department of Physics, University of Florida, USA
[c]Center for High Energy Physics, Peking University, China

I present our theoretical study[1] on the interactions among superfluid quasi-particles, as well as between superfluid quasi-particles and impurity particles. In recent work[2], we explored the possibility of using superfluid helium to directly detect sub-GeV dark matter (DM). I will discuss our modeling of quasi-particle production and thermalization processes, along with the sensitivity projections for generic DM direct detection experiments using nanoelectromechanical system (NEMS) oscillators. Currently, we are also comparing the theoretical formalism of phonon-roton interactions with the viscosity coefficient of superfluid helium. Based on current viscosity coefficient data, we aim to provide insights into the correctness of different solutions to this problem presented in the literature.

1. Matchev, K., Smolinsky, J., Xue, W., You, Y. (2022). Superfluid effective field theory for dark matter direct detection. Journal of High Energy Physics, 2022(5), 1-31.
2. You, Y., Smolinsky, J., Xue, W., Matchev, K., Saab, T., Gunther, K., Lee, Y. (2023). Signatures and detection prospects for sub-GeV dark matter with superfluid helium. Journal of High Energy Physics, 2023(7), 1-31.

TU1.3 Axion Wind Detection with the Homogeneous Precession Domain of Superfluid Helium Three

Christina Gao[a], William Halperin[b], Yonatan Kahn[a], Man Nguyen[b], Jan Schütte-Engel[a], and John William Scott[b]

[a]Department of Physics, University of Illinois Urbana-Champaign, Urbana, Illinois 61801, USA
[b]Department of Physics and Astronomy, Northwestern University, Evanston, Illinois 60208, USA

Axions and axion-like particles may couple to nuclear spins like a weak oscillating effective magnetic field, the "axion wind". Existing proposals for detecting the axion wind sourced by dark matter exploit analogies to nuclear magnetic resonance (NMR) and aim to detect the small transverse field generated when the axion wind resonantly tips the precessing spins in a polarized sample of material. We describe a new proposal using the homogeneous precession domain (HPD) of superfluid ^{3}He as the detection medium, where the effect of the axion wind is a small shift in the precession frequency of a large-amplitude NMR signal. A detailed study of the statistical and dynamical properties of the HPD system is included, as well as the effects of clock error and measurement error in a readout scheme using superconducting qubits and quantum metrology. Incorporating an optimal data-taking and analysis strategy, the proposed setup has competitive sensitivity to other axion wind experiments, such as CASPEr-Wind, for the axion masses below 100 neV.

1. Gao C., Halperin W., Kahn Y., Nguyen M., Schütte-Engel J., and Scott J. W. "Axion Wind Detection with the Homogeneous Precession Domain of Superfluid Helium-3". Physical Review Letters 129, 211801 (2022)

TU1.4 QUEST-DMC: Looking for Low Mass Dark Matter in Superfluid ^{3}He-B

M. T. Noble

Department of Physics, Lancaster University, Lancaster, LA1 4YB, UK

On behalf on the QUEST-DMC collaboratoration.

We present the results of the initial calibration run of the QUEST-DMC experiment that aims to detect low mass sub-GeV dark matter utilising superfluid ^{3}He-B as a target medium [1,2]. To detect interactions with dark matter we use bolometers each consisting of a 0.32 mL volume of helium with a vibrating wire resonator thermometer to detect the thermal energy deposited. To accurately reconstruct the energy deposited we have calibrated the bolometer's energy sensitivity using a vibrating wire heater inside the bolometer. The runs have been completed at pressures from 0 to 29 bar and superfluid temperatures of about 0.15 T/T_c. Using conventional readouts, we have achieved an energy threshold of 3.5 keV. We will discuss how we are using these results compared with predicted radiation backgrounds from GEANT4 simulations to construct the next generation detector for the full dark matter search, which will combine SQUID-based readout with low-background materials to achieve the best possible sensitivity.

1. QUEST-DMC collaboration, QUEST-DMC superfluid He detector for sub-GeV dark matter, Eur. Phys. J. C **84**, 248 (2024).
2. QUEST-DMC collaboration, QUEST-DMC: Background Modelling and Resulting Heat Deposit for a Superfluid Helium-3 Bolometer, J. Low Temp. Phys. accepted, (2024).

TU1.5 Gravity- and temperature-driven phase transitions in a model for collapsed axionic condensates

Sanjay Shukla[a], Akhilesh Kumar Verma [b], Marc E. Brachet[c], and Rahul Pandit[a]

[a]Department of Physics, Indian Institute of Science, Bangalore 560012, India
[b]Civil and Architectural Engineering, University of Miami, Coral Gables, Florida FL 33146, USA
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We show how to use the cubic-quintic Gross-Pitaevskii-Poisson equation (cq-GPPE)[1] and the cubic-quintic Stochastic Ginzburg-Landau-Poisson equation (cq-SGLPE)[1] to investigate the gravitational collapse of a tenuous axionic gas into a collapsed axionic condensate for both zero and finite temperature T. At $T = 0$, we use a Gaussian Ansatz for a spherically symmetric density to obtain parameter regimes in which we might expect to find compact axionic condensates. We then go beyond this Ansatz, by using the cq-SGLPE to investigate the dependence of the axionic condensate on the gravitational strength G at $T = 0$. We demonstrate that, as G increases, the equilibrium configuration goes from a tenuous axionic gas, to flat sheets or *Zeldovich pancakes*, cylindrical structures, and finally a spherical axionic condensate. Finally, we discuss how our cq-GPPE approach can be used to follow the spatiotemporal evolution of a rotating axionic condensate and also a rotating binary-axionic-condensate system; in particular, we demonstrate, in the former, the emergence of vortices at large angular speeds Ω and, in the latter, the rich dynamics of the mergers of the components of this binary system, which can yield vortices in the process of merging.

1. S. Shukla, A.K. Verma, M.Brachet, and R. Pandit. "Gravity- and temperature-driven phase transitions in a model for collapsed axionic condensates", Phys. Rev. D **109**, 063009, (2024).

TU2.1 Progress on LCMN thermometery

R. N. Baten, Y. Tian, E. N. Smith, and J. M. Parpia

Cornell University, Department of Physics, Ithaca, NY, USA

LCMN susceptibility thermometers offers high signal-to-noise with the use of SQUID pickup, and responsive temperature tracking in 3He experiments. A virtue of susceptibility LCMN susceptibility measurements is that the signal magnitude is primarily dependent on the fill factor. This provides the opportunity to design LCMN thermometers at a microscopic length scale for the purpose of local thermometery in superfluid 3He experiments. We will present our current signal-to-noise in LCMN SQUID thermometery as well as progress on local SQUID thermometry development. Time permitting I will discuss signal-to-noise in torsional oscillator measurements, and the development of quartz fork motion sensing with SQUID pickup.

TU2.2 Entanglement and noise in traveling wave Josephson parametric amplifiers

I. Lilja[a,b], E. Mukhanova[a,b], K. Petrovnin[a,b], A. Zyuzin[a,b], V. Vesterinen[c], and P. Hakonen[a,b]

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Continuous Variable states offer a promising approach for implementing quantum protocols because they allow for the creation of extensive networks of entangled states in addition to simple measurement techniques using homodyne and heterodyne detection.[1] Inter-modal entanglement can be created with various parametric systems based on Josephson junctions: Josephson Parametric Oscillators based on symmetric (DC SQUID) or asymmetric (SNAIL) elements and amplifiers based on non-linear transmission lines (TWPA).[2] By achieving highly entangled states in quantum-limited devices, one can enhance sensitivity in delicate measurements, such as two-level systems characterization at extremely low levels, including the single photon regime. I present the results of establishing a highly entangled large CV cluster state as a foundation for quantum information protocols. I show that the sufficient bandwidth of TWPA allows it to overcome spectral crowding problems and insufficient squeezing of generated states and hence to be operated in a near quantum-limit regime and achieve near- Genuine Multipartite Entangled states.

1. Braunstein, Samuel L., and Peter Van Loock. "Quantum information with continuous variables." Reviews of Modern Physics 77(2) (2005): 513.
2. Perelshtein, M. R., et al. "Broadband continuous-variable entanglement generation using a Kerr-free Josephson metamaterial." Physical Review Applied 18.2 (2022): 024063.

TU2.3 Immersing samples in helium-3, revisiting boundary resistance

A. Casey, P. Knappova, J. Saunders, J. Nyéki, and . L.V

Royal Holloway, University of London, UK

The thermal contact between liquid helium and solids is a critical factor in cooling both cryostats and experiments to ultralow temperatures. However there are still unanswered questions related to this boundary resistance. Acoustic mismatch theory predicts the thermal boundary resistance to have a stronger temperature dependence than found in many experimental measurements. The possibility of heat transfer via magnetic channels has been extensively investigated and discussed theoretically. Sintered metal powders of relatively high specific surface area are commonly used in these investigations, with the drawback that poor thermal conductance of helium within the sinter pores needs to be taken into account [1].
In this work we exploit our advances in thermometry and control of heat leaks to measure the thermal boundary resistance between small area metal samples (foils or wires) and liquid helium-3. This is similar to the approach taken many years ago [2], with the advantage of significantly lower area samples and the ability to reach lower temperatures through the reduction of heat leaks to a few fW. A compact SQUID-based current sensing noise thermometer is used to measure the increase in temperature of the foil on application of heater power (a few pW at low mK temperatures).

1. Autti, S., *et al.*, *Effect of the boundary condition on the Kapitza resistance between superfluid 3He-B and sintered metal*, Phys. Rev. B 102, 064508 (2020)
2. Avenel, O., *et al.*, *Improved Thermal Contact at Ultralow Temperatures between 3He and Metals Containing Magnetic Impurities*, Phys. Rev. Lett. 31, 76 (1973)

TU2.4 Thermal Relaxation Effect in the Nanopore Heat Exchanger for Dilution Refrigerator.

A. A. Temurjonov[a], T. Matsushita[a], M. Hieda[b], and N. Wada[a]

[a]Department of Physics, Nagoya University, Nagoya 464-8602, Japan
[b]College of Liberal Arts and Sciences, Tokyo Medical and Dental University, Ichikawa 272-0827, Japan

Heat exchangers for dilution refrigerator usually involve sintered 70 nm Ag powder which reduces Kapitza resistance due to its rather large specific area ∼1 m^2/g. On the other hand, as the mean free path of bulk He at low temperatures becomes larger than the distance between grains (∼70 nm), thermal resistance of the He mixture becomes significant due to the scattering of ^{3}He quasiparticles with grains. In previous study[1] we reported on nanopore heat exchanger (NHEx)[2], where both problems can be resolved. Thermal resistance measurements of NHEx pad showed one order smaller Kapitza resistance compared to conventional heat exchanger pad with the same size. Numerical simulations of total thermal resistance of pads showed 3-10 times smaller value for NHEx pad with 5% mixture inside pad. As ^{3}He has large heat capacity, it is needed enough time to effectively perform heat exchange between diluted mixture and pure ^{3}He. Therefore, further optimization of NHEx performance requires numerical simulations of the thermal relaxation effect in pads with diluted mixture of ^{3}He-^{4}He and pure ^{3}He, what will be presented in this talk.

1. A. A. Temurjonov et al. Performance Evaluation of the Nanopore Heat Exchanger for Dilution Refrigerator. J. Low Temp. Phys. (2024)
2. N. Wada, T. Matsushita, M. Hieda, JP Patent number 7128544. US Patent number 11796228. CN Patent application number 201980015009.0

TU2.5 Quasioptical Microwave Field Enhancement for Electron-on-Helium Qubits

N. Morais, M. Belianchikov, and D. Konstantinov

Quantum Dynamics Unit, Okinawa Institute of Science and Technology, Japan

The recent progress in quantum information technology has intensified the search for stable, high-fidelity qubits. Electrons on liquid helium-4 (^{4}He) surface present an untapped yet promising avenue for implementing qubits or spin state readouts through spin-orbit interactions [1]. However, a significant challenge obstructing their practical use is the difficulty in achieving precise and controlled manipulation.
A small ensemble of electrons is stored in a microchannel filled with liquid ^{4}He. These electrons are bound to the surface by an attractive $1/z$ potential from its polarization within the liquid ^{4}He. This results in a spectrum of anharmonic Rydberg atom-like states. The photon energy required for a single electron to transition from the ground state to the first excited state corresponds to a frequency of 126 GHz. According to the Fermi golden rule, the transition probability per unit of time scales quadratically with the electric field magnitude; thus, increasing it accelerates electron dynamics on liquid ^{4}He. We propose a novel approach to enhance and precisely control the microwave field using quasioptical techniques. Utilizing a standard horn antenna paired with an elliptical silicon (Si) lens, our research features a specially designed photoconductive bow-tie antenna integrated into our microchannel device on a chip. Using only the horn antenna and Si lens, we predict a field amplification of 26 dB. Simulation results forecast additional enhancements ranging from 17 to 36 dB for microchannel widths of 10 and 2 μm, respectively. This tailored enhancement pushes the boundaries of this type of qubit implementation.

1. E. Kawakami, J. Chen, M. Benito, and D. Konstantinov. "Blueprint for quantum computing using electrons on helium". Phys. Rev. Applied 20, 054022 (2023).

5. List of presenters

Ahangarfirouzjaei, F.	TH5.1
Alihosseini, Y.	FR4.1
Arrayas, M.	TH5.2
Asakawa, K.	TH5.3
Autti, S.	TH1.2
Bagnato, V.	MO4.2
Baten, R.	TU2.1
Blaha, J.	TH5.4
Boettcher, I.	FR2.3
Casey, A.	TU2.3
Chandrasekhar, V.	SA1.4
Choi, H.	FR3.4
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