International Conference on Quantum Fluids & Solids

QFS2023

9th-15th August, 2023

Manchester, UK

MANCHESTER 1824

The University of Manchester

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1. General information

Welcome to QFS2023

We are pleased to welcome you to the International Conference on Quantum Fluids and Solids, at the University of Manchester!

Emergency contacts

To reach the organizers, please email or call: qfs2023@manchester.ac.uk, +44 771 780 4503. All emergency services (police, fire, ambulance) can be contacted by calling 999. For urgent help on campus, you can contact University Security on +44 161 306 9966.

Wireless Network

If your institution is an eduroam member, you will be able to use your home institution credentials to connect to this network. Alternatively, delegates can register for free with the University's guest network, UoM Guest: open the web browser and follow the instructions. You can register with your Google, Facebook or Twitter account, or via a text (SMS) message sent to your phone.

Conference Venue

All conference activities, except for the Conference Dinner, will take place in Engineering Building A, on Booth Street East. Interactive and pdf maps of both the Engineering Building and the campus can be accessed via this link:
http://www.manchester.ac.uk/discover/maps/.
The registration desk, catering stations and the poster sessions will be located in the South Entrance foyer, on the ground floor. The talks will be held in Lecture Theatre A (2A.040, just above the foyer), accessible from the first and second floor. Room GA.056 is available as a free space on the ground floor.

Registration

Delegates will collect badges at registration which will be open 16:00-18:30 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

Files in ppt, pptx or pdf format should be uploaded to the computer in the Lecture Theatre before the beginning of the session. Files can be uploaded in advance using the google form https://forms.gle/xsHTPopMWTAFJKRJA

Posters

Posters should be put up not later than the morning coffee break and removed before 19:00 (except for Saturday 12 August). Velcro for posters will be provided by the organisers. No drawing pins, staples, sticky pads or any other form of adhesive should be used.

Conference Dinner

The Conference Dinner, sponsored by Oxford Instruments, will take place in the University's Whitworth Hall on Monday 14th of August. This is located on the first floor of the Whitworth Building, next to Manchester Museum, and accessible via the entrance under the Queen's Arch on Oxford Road.

Eating Arrangements

Breakfast is available at halls of residence and hotels, as well as at other places on or near campus. Coffee and snacks will be available at the conference venue in the morning (10:30) and afternoon (15:00). Catered lunches will be provided at the venue, for the four full days of talks, between 12:30 and 13:30. For dinners, participants will be on their own to explore Manchester's wide range of restaurants, many of which are easily accessible on foot. All food outlets available on campus, including the cafe inside our venue space, are listed: https://www.foodoncampus.manchester.ac.uk/ and can be located on the campus map. The organisers' list of restaurants off campus is here: https://qfs2023.org/restaurants/.

Travel information

Bus: Tickets can be purchased from the bus drivers, using cash or card (£2 for a single journey). The bus will only stop if it is waved down. To get off the bus, you must press the red 'stop' button right before your desired stop. Many bus routes operate on Oxford Road with a stop *Aquatic Centre* near the Venue.

Bus 50 connects Canterbury Court (stop: *Anson Road/near Denison Road*) and the conference venue (stop: *Upper Brook Street / opposite Booth Street East*). It has a frequency of 12 minutes, operates Monday-Sunday, and full timetables can be accessed here:
https://www.stagecoachbus.com/routes/greater-manchester/50/east-didsbury-media-city/xjao050.i.

Taxi: There are a number of taxi firms operating in the local area. Examples:
Street Cars Manchester (0161 228 7878), Uber (app only, www.uber.com/gb/en/ride/).

Parking: If you are driving to Manchester, please park at the multistorey car park on Booth Street East, postcode M13 9SS. It is open from 6:00 am to midnight, 7 days per week (max height 2.1 metres). Drivers should collect a ticket on entry and pay at one of the machines prior to exiting at the end of the day.

2. Programme Overview

Wednesday 9 August

16:00-19:00 REGISTRATION & WELCOME RECEPTION (Engineering Building, Booth St E)

Thursday 10 August

9:00-9:20 OPENING WELCOME
9:20-10:50 TH1 Superfluid ^{4}He and ^{3}He
COFFEE
11:20-12:50 TH2 Superfluid ^{3}He
12:50-13:50 LUNCH
13:50-15:00 TH3 Exciton-Polaritons
COFFEE
15:30-17:00 TH4 Quantum Vortex
17:00-18:30 TH5 POSTERS & DRINKS 1: Bulk and Confined Quantum Gases, Liquids & Solids

Friday 11 August

9:00-10:30 FR1 Confined ^{4}He
COFFEE
11:00-12:10 FR2 Quantum Fluids for Cosmology 1
12:10-13:10 LUNCH
13:10-14:40 FR3 Quantum Turbulence 1
COFFEE
15:10-17:00 FR4 A.F. ANDREEV Memorial and Novel Superfluids/Superconductors
17:00-18:30 FR5 POSTERS & DRINKS 2: Electrons on He/Ne, Cryogenic Techniques, Superfl Optomechanics, Q. Fluids for Cosmology

Saturday 12 August

9:00-10:15 SA1 Quantum Gases
COFFEE
10:45-12:15 SA2 Confined Superfluid Helium
12:15-13:15 LUNCH
13:15-13:30 GROUP PHOTO
13:30-15:00 SA3 Electrons on Helium and Neon
COFFEE
15:30-17:00 SA4 Quantum Turbulence 2
17:00-18:30 SA5 POSTERS & DRINKS 3: Quantum Vortices and Turbulence, Novel Superfluids and Superconductors

Sunday 13 August

11:00-13:00 & 14:00-16:00 EXCURSIONS

Monday 14 August

9:00-10:30 MO1 Quantum Fluids for Cosmology 2
COFFEE
11:00-12:30 MO2 Superfluid Optomechanics
12:30-13:30 LUNCH
13:30-15:00 MO3 Superfluid ^{3}He in Aerogel
COFFEE
15:30-17:35 MO4 HALL & VINEN Memorial
19:00-22:30 CONFERENCE DINNER (Whitworth building, Oxford Road)

Tuesday 15 August

9:00-10:10 TU1 Cryogenic Techniques
COFFEE
10:40-11:50 TU2 Quantum Solids
11:50-12:30 CLOSING CEREMONY
12:30 PACKED LUNCH

3. Programme

Thursday 10 August

9:00-9:20 OPENING WELCOME

9:20-10:50 SESSION TH1 Superfluid ^{4}He and ^{3}He, chair Richard Haley

9:20 TH1.1 Jules Grucker, Brillouin spectroscopy of metastable superfluid helium-4

9:45 TH1.2 Jeevak Parpia, Observation of fluctuations in the viscosity just above the superfluid transition in ^{3}He

10:10 TH1.3 Jim Sauls, Pairing fluctuation effects on quasiparticle transport above T_c

10:30 TH1.4 Lev Melnikovsky, Overcritical Fermi superfluids

10:50-11:20 COFFEE

11:20-12:50 SESSION TH2 Superfluid ^{3}He, chair John Saunders

11:20 TH2.1 Anton Vorontsov, Superfluid He-3 suppression near atomically smooth surfaces

11:45 TH2.2 Alexander Shook, Measurement of ^{3}He-A critical velocity in micron-scale slabs

12:10 TH2.3 Dmitry Zmeev, Superconducting nano-oscillators fabricated with wire drawing technology

12:30 TH2.4 Yutaka Sasaki, Spectroscopic imaging study on the domain structure in superfluid ^{3}He

12:50-13:50 LUNCH

13:50-15:00 SESSION TH3 Exciton-Polaritons, chair Carlo Barenghi

13:50 TH3.1 Marzena Szymańska, Novel non-equilibrium phenomena in quantum fluids of light

14:15 TH3.2 Kosuke Yoshioka, Bose-Einstein condensation of excitons in a bulk semiconductor at sub-kelvin temperatures

14:40 TH3.3 Hyoungsoon Choi, Controlling exciton-polariton vortices with orbital angular momentum of light

15:00-15:30 COFFEE

15:30-17:00 SESSION TH4 Quantum Vortex, chair Wei Guo

15:30 TH4.1 Sergei Kafanov, Non-linear dynamics of the trapped quantum vortex in superfluid ^{4}He

15:55 TH4.2 Vladimir Eltsov, Probing superfluid ^{3}He with a nanoelectromechanical oscillator

16:20 TH4.3 Yosuke Minowa, Quantized vortices visualized using silicon nanoparticles in superfluid helium

16:40 TH4.4 Ken Obara, Structure of superfluid suction vortex

17:00-18:30 POSTERS 1 TH5 Bulk and Confined Quantum Gases, Liquids and Solids

TH5.1 Filip Novotny, Influence of geometry on 2D turbulence in superfluid ^{4}He

TH5.2 William Freitas e Silva, Neural network-based trial function for bosonic systems: application to ^{4}He clusters

TH5.3 Oleg Kirichek, Direct observations of pure ^{4}He and ^{3}He in ^{4}He mixture films using neutron reflection.

TH5.4 Vitor Zampronio Pedroso, On the second layer of He-4 adsorbed on graphite: a shadow wave function approach.

TH5.5 Keiya Shirahama, Dielectric and elastic anomalies in helium films

TH5.6 Atsuki Kumashita, Search for the gas-liquid critical point in ^{3}He monolayer on graphite

TH5.7 Taku Matsushita, Spin diffusion of dilute ^{3}He fluid in ^{4}He-precoated 1D nanochannels

TH5.8 Jere Mäkinen, Experimental study of ^{3}He confined within a nematic carbon nanotube array

TH5.9 Riku Rantanen, Three dimensional Ginzburg-Landau calculations of vortex structures in ^{3}He-B

TH5.10 Daksh Malhotra, Nanofluidic device for experimental realisation of the polar phase of superfluid ^{3}He

TH5.11 Yasumasa Tsutsumi, Analytical expression of Green's function for superfluid ^{3}He B phase with surface bound state under magnetic field

TH5.12 Petri Heikkinen, QUEST-DMC: Early-Universe phase transitions in nanoconfined superfluid helium-3

TH5.13 Lev Levitin, Tuning the phase diagram of superfluid ^{3}He with electric field

TH5.14 Samuli Autti, Quasiparticle transport in a two-dimensional boundary superfluid

TH5.15 Vladislav Zavjalov, Thermal transport between and within surface layers of superfluid ^{3}He-B

TH5.16 Luke Whitehead, Scaling the edge of superfluid ^{3}He-B

TH5.17 Aleksei Semakin, Experiments with hydrogen atoms at ultra-low energies

TH5.18 Cameron Wetzel, Studies of the structures of nitrogen-neon nanoclusters immersed into superfluid helium-4

TH5.19 Thomas Flynn, Quantum droplets in imbalanced atomic mixtures

TH5.20 Gary Liu, Collective-mode excitations and nonlinear dynamics in an attractive Bose-Bose mixture

TH5.21 Jack Griffiths, Machine learning methods in computational physics

TH5.22 Andrei Golov, Vacancion transport of charges in solid bcc and hcp helium

TH5.23 Jan Nyeki, The ^{4}He supersolid in two dimensions: a status report

9:00-10:30 SESSION FR1 Confined ^{4}He, chair Keiya Shirahama

9:00 FR1.1 Emil Varga, Finite-size effects and nonlinear behaviour in strongly confined superfluid helium

9:25 FR1.2 Akira Yamaguchi, Structural study of two-dimensional helium on graphite with synchrotron radiation X-rays

9:50 FR1.3 Adrian Del Maestro, Atomically thin superfluid and solid phases for atoms on strained graphene

10:10 FR1.4 Eunseong Kim, A novel experimental platform for unveiling quantum phenomena in helium films adsorbed on graphite

10:30-11:00 COFFEE

11:00-12:10 SESSION FR2 Quantum Fluids for Cosmology 1, chair Andrew Casey

11:00 FR2.1 Swati Singh, Searching for ultralight dark matter using superfluid helium optomechanical systems

11:20 FR2.2 Dan McKinsey, HeRALD: Measurement of dark matter scattering events in superfluid helium-4 through quantum evaporation and energy-resolved single photon detection

11:45 FR2.3 Elizabeth Leason, QUEST-DMC: low mass dark matter search with superfluid helium-3

12:10-13:10 LUNCH

13:10-14:40 SESSION FR3 Quantum Turbulence 1, chair Ladislav Skrbek

13:10 FR3.1 Vanderlei Bagnato, Characterization and universal scaling properties of a turbulent atomic superfluid

13:35 FR3.2 Wei Guo, Visualization study of the law of wall in superfluid helium-4

14:00 FR3.3 Dario Ballarini, 2D quantum turbulence in a fluid of light

14:20 FR3.4 Courtney Elmy, Flying balls in superfluid helium

14:40-15:10 COFFEE

15:10-17:00 FR4 ANDREEV Memorial & Novel Superfluids/Superconductors, chair Jim Sauls

15:10-15:50 FR4.1 ALEXANDER ANDREEV Memorial, speakers: Jim Sauls, George Pickett, Igor Todoshchenko

15:50 FR4.2 Shuqiu Wang, Visualizing the zero-energy surface Andreev bound states of spin-triplet superconductor UTe_2

16:15 FR4.3 Lev Levitin, Unconventional superconductivity underpinned by antiferromagnetism in $YbRh_2Si_2$

16:40 FR4.4 Priya Sharma, Light induced magnetism via the inverse Faraday effect

17:00-18:30 POSTERS 2 FR5 Electrons on He & Ne, Cryogenic Techniques, Superfluid Optomechanics, Quantum Fluids for Cosmology

FR5.1 Alex Jones, Measurements of helium mixtures by neutron absorption

FR5.2 Azimjon Temurjonov, Performance evaluation of the nanopore heat exchanger

FR5.3 Roch Schanen, Development and testing of a low-frequency, high-amplitude, torsional oscillator for cryogenic studies.

FR5.4 Richard Down, Carbon footprint of the helium recovery system at the ISIS neutron and muon source

FR5.5 Rasul Gazizulin, Design of He-3 immersion cell to study low-dimensional electron systems

FR5.6 Andrew Casey, Study of thermal boundary resistance between ^{3}He and solids at ultralow temperatures

FR5.7 Saba Khan, Vibrating carbon nanotubes: a nanomechanical probe to study quantum phenomena in superfluid

FR5.8 Scott Henderson, Probing superfluid ^{4}He with oscillating carbon nanotubes

FR5.9 Ilya Golokolenov, Fully suspended mechanical probes for quantum fluids

FR5.10 Camille Mikolas, Two-dimensional plasmons in microchannel confined electrons on helium

FR5.11 Austin Schleusner, Correlated transport of electrons on helium through a gate-defined island

FR5.12 Jui-Yin Lin, Fast charge sensing for quantum-state detection in electrons on helium

FR5.13 Tomoyuki Tani, Rydberg transition of surface state electrons on liquid ^{4}He sensed by RF-reflectometry

FR5.14 Mikhail Belianchikov, Resonant image charge detection for e^-@He qubit

FR5.15 Asher Jennings, Integration of a cryogenic LC circuit for image-charge detection for surface electrons on helium

FR5.16 Tiffany Liu, Electron transport on thin helium films across mm-long transport line

FR5.17 Auratrik Sharma, Proposal towards transient enhancement of electron density above liquid helium into the quantum degenerate regime

FR5.18 Dillip Pradhan, focusing ultrasound in superfluid helium-4 using a Fresnel zone plate

FR5.19 Neda Shamim, Effect of convective flow on the dynamics of multielectron bubbles in liquid Helium-I

FR5.20 Shriganesh Neeramoole, Using a cylindrical piezoelectric transducer to focus ultrasound in superfluid helium

FR5.21 Raymond Harrison, Trapping sound with light

FR5.22 Gary Liu, Coherent structures and turbulence in fuzzy dark matter haloes

FR5.23 Kenta Asakawa, Anisotropic collective mode of self-gravitating Bose-Einstein condensates

FR5.24 Tineke Salmon, Superfluid helium-3 bolometers for a direct dark matter search

FR5.25 Zara Graham Jones, Proposal for analogue gravity using thin superfluid ^{4}He films

9:00-10:15 SESSION SA1 Quantum Gases, chair Vanderlei Bagnato

9:00 SA1.1 Thomas Bland (Innsbruck), Rotating dipolar quantum gases: vortices, supersolids, and glitches

9:25 SA1.2 Nick Keepfer (Newcastle), Dimensionality crossover in a weakly interacting atomic Bose gas and the dynamics of quantum droplets: a study of phase transitions

9:50-10:15 SA1.3 DISCUSSION OF DIVERSITY & INCLUSION IN PHYSICS, speaker Priya Sharma

10:15-10:45 COFFEE

10:45-12:15 SESSION SA2 Confined Superfluid Helium, chair Hiroshi Fukuyama

10:45 SA2.1 Petri Heikkinen, Superfluid helium-3 under mesoscopic confinement: low magnetic fields and phase transitions

11:10 SA2.2 Takeshi Mizushima, Thermal generation of spin currents in superfluid ^{3}He

11:35 SA2.3 Keiya Shirahama, Multiple phase-slip phenomenon in ^{4}He superflow through a well-defined microchannel

11:55 SA2.4 Junko Taniguchi, Superfluidity and Luttinger-liquid behavior of helium in 1D limit

12:15-13:15 LUNCH
13:15-13:30 GROUP PHOTO

13:30-15:00 SESSION SA3 Electrons on Helium and Neon, chair Stephen Lyon

13:30 SA3.1 Dafei Jin, Single electrons on solid neon: a long-coherence high-fidelity solid-state qubit platform

13:55 SA3.2 Denis Konstantinov, Rydberg-state detection for electrons-on-helium qubits

14:20 SA3.3 Johannes Pollanen, High-frequency collective dynamics of electrons on helium

14:40 SA3.4 Ambarish Ghosh, Stability and dynamics of multielectron bubbles in liquid helium

15:00-15:30 COFFEE

15:30-17:00 SESSION SA4 Quantum Turbulence 2, chair Viktor Tsepelin

15:30 SA4.1 Zoran Hadzibabic, Quantum gas in a box

15:55 SA4.2 Giorgio Krstulovic, Turbulent steady states in Bose-Einstein condensates

16:20 SA4.3 Victor L'vov, HVBK equation-based theory of developed counterflow superfluid turbulence

16:40 SA4.4 Hiromitsu Takeuchi, Drag force due to quantum viscosity in superfluid ^{4}He at zero temperature

17:00-18:30 POSTERS 3 SA5 Quantum Vortices and Turbulence, Novel Superfluids and Superconductors

SA5.1 Mehdi Zarea, Electromagnetic response of superconducting cavities

SA5.2 James Sauls, Electron teleportation in Kitaev wire with Coulomb interaction

SA5.3 James Sauls, Is $YbRh_2Si_2$ a spin-triplet superconductor?

SA5.4 John Saunders, Determination of complex conductivity of superconducting $YbRh_2Si_2$ by measurements of low frequency ac magnetic susceptibility.

SA5.5 Lev Levitin, Electrical transport study of unconventional superconductivity in $YbRh_2Si_2$

SA5.6 Ryusuke Ikeda, Higher Landau level vortex state realized in superconducting FeSe

SA5.7 Hiromichi Kobayashi, Effect of different mutual friction models on velocity fluctuation of normal-fluid in superfluid helium-4

SA5.8 Issei Doki, Cascade and isotropization of momentum distribution of turbulence in two-component Bose-Einstein condensates

SA5.9 Yuto Sano, Rotating turbulence in Bose-Einstein condensates

SA5.10 Satoshi Yui, Vortex-filament bundle induced by normal-fluid turbulence in turbulent superfluid helium-4

SA5.11 Weican Yang, Universal defect density scaling in an oscillating dynamic phase transition

SA5.12 Tomo Nakagawa, Dynamics of pinned quantized vortices in superfluid ^4He in microelectromechanical oscillator

SA5.13 Hiromitsu Takeuchi, Isolated fractional skyrmions generated by Kelvin-Helmholtz instability in a magnetic quantum gas

SA5.14 Hiromitsu Takeuchi, Critical velocity for quantized vortex formation in a superfluid wake with a plate obstacle

SA5.15 Richard Tattersall, Non-equilibrium dynamics of vortices in two-dimensional quantum fluids

SA5.16 Piotr Stasiak, Energy and helicity transfer in superfluid helium

SA5.17 Sam Patrick, Stability of quantised vortices in two-component condensates

SA5.18 Ken Obara, Diffusion of vortex tangle in a narrow tube due to thermal counter-flow

SA5.19 Ken Obara, Vortex emission from counter flow turbulence in superfluid helium 4

SA5.20 Kimitoshi Kono, Radial thermal counter flow in superfluid ^4He studied by means of a quartz tuning fork

SA5.21 Šimon Midlik, Vibrating micro-wire resonators used as a local probe of quantum turbulence in superfluid ^4He

SA5.22 Manuel Arrayas, Shaking and stirring helium-4 with a superconducting levitating probe

SA5.23 Chris Goodwin, Visualization of the motion of small particles in superfluid ^4He at $T < 1$ K

SA5.24 Matt Doyle, Modelling turbulent flow of superfluid ^4He past a rough solid wall in the $T = 0$ limit

SA5.25 Sio Lon Chan, A universal profile of a beam of charged vortex rings in superfluid ^4He in the $T = 0$ limit

9:00-10:30 SESSION MO1 Quantum Fluids for Cosmology 2, etc., chair William Halperin

9:00 MO1.1 Mark Hindmarsh, The AB transition in superfluid ^{3}He and cosmological phase transitions

9:25 MO1.2 Patrik Svancara, Superfluid bathtub vortex: a potential simulator of a quantum black hole

9:50 MO1.3 Hikaru Ueki, Searching for axions and nonlinear QED with high-Q superconducting resonators

10:10 MO1.4 Alexei Chepelianskii, Landau level spectroscopy and edge magnetoplasmons on electrons on helium

10:30-11:00 COFFEE

11:00-12:30 SESSION MO2 Superfluid Optomechanics, chair Emil Varga

11:00 MO2.1 Cristopher Baker, Nonlinear waves and solitons in superfluid helium films

11:25 MO2.2 Yogesh Patil, Optomechanics with magnetically levitated drops of liquid ^{3}He and ^{4}He

11:50 MO2.3 Sebastian Spence, Three-tone coherent microwave optomechanical measurement of a superfluid Helmholtz resonator

12:10 MO2.4 Andrew Fefferman, Microwave optomechanics and cryogen-free nuclear demagnetization refrigeration

12:30-13:30 LUNCH

13:30-15:00 SESSION MO3 Superfluid ^{3}He in Aerogel, etc., chair Jeevak Parpia

13:30 MO3.1 John Scott, Magnetic susceptibility of Andreev bound states in superfluid ^{3}He-B in anisotropic aerogel

13:55 MO3.2 Evgeny Surovtsev, Oscillations of nematic aerogel in a superfluid medium

14:20 MO3.3 Man Nguyen, Superfluid ^{3}He in planar and nematic aerogels

14:40 MO3.4 Christopher Lawson, Neutron imaging of an operational dilution refrigerator

15:00 – 15:30 COFFEE

15:30-17:35 SESSION MO4 HALL & VINEN Memorial, chair Peter McClintock

15:30 MO4.1 Andrei Golov, The legacy of Henry Hall and Joe Vinen in quantum fluids and beyond

15:50 MO4.2 George Pickett, Henry Hall and the early days of superfluid ^{3}He at Manchester

16:15 MO4.3 Carlo Barenghi, Quantum turbulence: the legacy of W.F. Vinen

16:35 MO4.4 Ladislav Skrbek, Collective dynamics of ions and vortices in He II in experiments of Joe Vinen

16:55 MO4.5 Makoto Tsubota, Studies on quantum turbulence with Vinen

17:15 MO4.6 Jere Mäkinen, Rotating quantum wave turbulence and onset of the Kelvin wave cascade

19:00-22:30 CONFERENCE DINNER (Whitworth building, Oxford Road)

Tuesday 15 August

9:00-10:10 SESSION TU1 Cryogenic Techniques, chair Andrew Fefferman

9:00 TU1.1 Hiroshi Fukuyama, Development of the continuous sub-millikelvin refrigerator

9:25 TU1.2 Jan Nyeki, High performance rapid turn-around cryogen-free microkelvin platform: unlocking the sub-1mK temperature range for quantum materials research

9:50 TU1.3 Jonathan Prance, On-chip magnetic cooling of nanoelectronic devices

10:10-10:40 COFFEE

10:40-11:50 TU2 Quantum Solids, chair Xavier Rojas

10:40 TU2.1 Igor Todoshchenko, Acoustic Casimir effect and fate of thermodynamics in mesoscopic matters

11:05 TU2.2 Anatoly Kuklov, Supertransport in the core of dislocations in solid helium-4

11:30 TU2.3 Vladimir Khmelenko, Influence of ortho-H_2 molecules on accumulation and spatial diffusion of H atoms in solid H_2 films

11:50-12:30 CLOSING

12:30 PACKED LUNCH

4. Abstracts

4.1 Invited Oral Presentations: Thursday 10th August

TH1.1 **Brillouin Spectroscopy of metastable superfluid helium-4**

Lionel Djadaojee, **Jules Grucker**

Laboratoire Kastler Brossel, ENS - Sorbonne Université - CNRS - Collège de France, Paris, France

Because liquid helium at low temperature is the purest possible liquid, it is a model system to probe deep condensed matter metastable states and homogeneous nucleation phenomena in quantum fluids. Homogeneous nucleation theory is a cosmological issue as it could apply to possible phase transitions in the early universe. The absence of impurities and the little thermal energy available in the fluid make of superfluid helium-4 an appealing candidate to reach experimentally the close vicinity of the spinodal limit where the compressibility of the liquid diverges making it mechanically totally unstable even in the limit $T \rightarrow 0$.

Our experiment produces metastable (negative pressure) states of superfluid ^{4}He by focusing acoustic waves within the bulk of the liquid. Recently, we have developed and implemented a finely spatially and temporally resolved stimulated Brillouin spectrometer capable of measuring optically the compressibility of the metastable states of superfluid helium-4. This has enabled us to estimate the destabilization (cavitation) pressure of liquid helium-4 at $T \sim 1$ K. Our results clearly disagree with previous estimates made by more indirect methods than ours and suggest that the quantized vortices of the superfluid could serve as phase nucleation sites for the cavitation bubbles[1].

[1] Lionel Djadaojee and Jules Grucker. Brillouin spectroscopy of metastable superfluid helium- 4, Phys. Rev. Lett., **129**, 129125301 (2022).

TH1.2 **Observation of Fluctuations in the viscosity just above the superfluid transition in ^{3}He**

Rakin Baten, Yefan Tian, Eric Smith, Erich Mueller, **Jeevak Parpia**

Department of Physics, Cornell University, Ithaca, USA

By monitoring the quality factor of a quartz tuning fork oscillator we have observed a fluctuation-driven reduction in the viscosity of bulk ^{3}He in the normal state near the superfluid transition temperature, T_c. These fluctuations, which are only found within 100 μK T_c, play a vital role in the theoretical modeling of ordering; they encode details about the Fermi liquid parameters, pairing symmetry, and scattering phase shifts. They will be of crucial importance for transport probes of the topologically nontrivial features of superfluid ^{3}He under strong confinement. We characterize the temperature and pressure dependence of the fluctuation signature, finding a remarkable collapse.

TH1.3 Pairing Fluctuation Effects on Quasiparticle Transport above T_c

James Sauls[1,2], Wei-Ting Lin[1,3]

[1]Physics and Astronomy, Northwestern University, Evanston, IL, USA
[2]Hearne Institute of Theoretical Physics, Louisiana State University, Baton Rouge, LA, USA
[3]Physics, University of Michigan, Ann Arbor, MI, USA

For temperatures just above the transition from a normal Fermi liquid to a superfluid, long-lived Cooper pairs ("pair fluctuations") open a new channel for quasiparticle scattering. In the late 1970's Emery proposed a heuristic theory of pre-cursor signatures of higher angular momentum pairing on transport processes with the goal of identifying the pairing symmetry of the recently discovered superfluid phases of ^{3}He. Until recently a first-principles theory of the effects of long-lived pairing fluctuations on quasiparticle transport processes was lacking [1]. I briefly outline our theory for the leading-order corrections to transport processes from quasiparticle-pair-fluctuations scattering based on a quasiclassical reduction of Keldysh's formulation of nonequilibrium quantum transport theory for strongly interacting Fermi liquids, then present new results and predictions of pairing fluctuation effects on transport coefficients and nonequilibrium processes in liquid ^{3}He and other strongly interacting Fermi superfluids.

This research was supported by National Science Foundation Grant DMR 1508730.

[1] W.-T. Lin and J. A. Sauls, Prog. Theor. Exp. Phys. 2022, 033I03 (2022).

TH1.4 Overcritical Fermi Superfluids

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According to Landau criterion, the velocity of superflow with respect to the reservoir walls is limited by a critical value. Beyond this limit the quasiparticles with negative energy are spontaneously created. If some mechanism puts a bound on the quasiparticle population, then a phase transition occurs at the Landau critical velocity. The nature of the emerging overcritical state depends on the quasiparticle statistics. In the Bose case, in presence of suitable repulsive interaction, the fluid may become nonuniform. Overcritical Fermi superfluid is stabilized by the Pauli principle. Equilibrium at zero temperature corresponds to a non-vanishing normal component formed by fully occupied negative energy Bogolyubov quasiparticle levels.

We explore the exact nonlinear superfluid hydrodynamics and particularly investigate the sound propagation in overcritical ^{3}He-B at zero temperature for small over-speed. Like the usual superfluid at rest, this system has two linear dispersion acoustic modes:

#1 The fast one is effectively the conventional sound, slightly entrained downstream by the quasiparticle flow.
#2 The slow mode, naturally referred to as the second sound, strongly depends on the overspeed and is essentially anisotropic. It is supported by the normal component and its velocity is close to the velocity of the latter. Just like the conventional second sound, the fluid density remains constant in these waves, but unlike the conventional second sound, no temperature oscillations are associated with them.

TH2.1 Superfluid He-3 suppression near atomically smooth surfaces

Anton Vorontsov

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Quasiparticles' scattering on surfaces is the dominant pairbreaking mechanism in unconventional superfluids in confinement. It is also the main player that determines the spectrum of the topological surface states of the quasiparticles. Typically, smooth atomic surfaces are thought to be minimally pairbreaking. We consider scattering on smooth surfaces with lattice periodicity on the order of the Fermi wavelength of He-3, where diffraction effects may lead to strong back-scattering of quasiparticles and to significant suppression of the transition temperature. We show how the periodic structure and the electronic density corrugation of the surface atomic layer affect the superfluid transition temperature of He-3A in thin slabs, and investigate the Andreev bound states that appear due to the diffraction effects. Some of these conditions and effects may be realizable in the ongoing experiments on He-3 in confinement.

TH2.2 Measurement of ^{3}He-A Critical Velocity in Micron-Scale Slabs

Alexander Shook, John Davis

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One of the defining features of superfluidity is dissipationless flow, which arises due to gaped elementary excitations. In superfluid ^{3}He-A the gap closes at nodes aligned with a spatially correlated anisotropy axis. In bulk systems, and cylindrical pores, dissipation may result due to the re-orientation of this axis in response to flow. In such systems dissipation either occurs at arbitrarily low velocities, or above a new velocity scale below the Landau critical velocity. We report on critical velocity measurements of ^{3}He-A confined to thin slabs of 750 and 1800 nm using a driven fourth-sound Helmholtz resonance. The anisotropy axis is strongly pinned by the boundary conditions allowing the Landau critical velocity to be probed in the absence of dynamic textures. The degree of gap suppression due to the boundaries can be inferred from the difference in Landau critical velocity between the two slabs.

TH2.3 **Superconducting Nano-oscillators Fabricated with Wire Drawing Technology**

Samuli Autti[1], Marie Connelly[1], Courtney Elmy[1], James Gorman[1], Richard Haley[1], Asher Jennings[2], George Pickett[1], Jonathan Prance[1], Tineke Salmon[1], Jack Slater[1], Evgeny Surovtsev[3], Michael Thompson[1], Viktor Tsepelin[1], Vladislav Zavjalov[1], **Dmitry Zmeev**[1]

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Fabricating superconducting nanomechanical resonators for quantum research, detectors and devices traditionally relies on a lithographic process, resulting in oscillators with sharp edges and a suspended length limited to a few 100 μm.

Here we report a low-investment top-down approach to integrating NbTi nanowire resonators in an electric circuit of choice. The wires are made by drawing multifilament superconducting cables through a series of diamond dies to the desired diameter. The filaments of the cable are isolated by etching the copper matrix, transported to a desired location and bonded to contact pads to form an electro-mechanical resonator. The suspended lengths of the nanowires can be up to several millimetres and their diameters down to 100 nm, leading to aspect ratios of over 10000. The nanowires possess high critical currents and fields, making them a natural choice for magnetomotive actuation and sensing. The resulting oscillators are inherently strain-free, leading to oscillators with resonant frequencies of a few kHz. This fabrication technique is independent of the substrate material, dimensions and layout and can readily be adapted to make nanowire resonators from any metal or alloy with suitable yield strength.

A circular cross-section of our wires means that they can operate at higher velocities before reaching the critical velocity in ^{3}He and allow for a robust description of the flow dynamics. We report the first results of using these wires in both ^{3}He and ^{4}He, including detection of turbulence in ^{4}He and size effect of the nanowire approaching the coherence length in ^{3}He.

TH2.4 **Spectroscopic imaging study on the domain structure in superfluid ^{3}He**

Yuto Ikegai[1], Yuya Hino[1], Natsuki Hara[1], Hayato Ishikawa[1], Zeju Xu[1], Takeo Takagi[2], **Yutaka Sasaki[1]**

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[2]Department of Applied Physics, University of Fukui, Fukui, JAPAN

Superfluid ^{3}He-A confined in narrow gapped parallel plates under in-plane magnetic field is supposed to hold an almost uniform texture, in which both ***l*** and ***d*** vectors orient in perpendicular to the plane. However, in the real experiment, we found that domains with either forward or backward orientation of the vector coexist and hold thin domain wall between them. Standard magnetic resonance imaging (MRI) measurement showed the real space image of the domain wall as a dark line in a 2D-projection view. We attributed the line as a dipole-locked soliton, which connects between forward and backward domains. Recently we have developed much elaborated measurement scheme, magnetic resonance spectroscopic imaging (MRSI), which provides spectra for any specified locations of the sample. The extracted local resonance frequency and linewidth provided rich information in understanding the nature of the object. With the help of improved sensitivity, we found the existence of several kind of domains and domain walls in the texture of the sample. One of dipole-locked domains showed full amount of dipole shift and narrowest NMR linewidth, while the other showed broader linewidth with the same amount of dipole shift. We also find other kind of domain wall, which appear with weaker intensity than previously found. Structure of those textural objects will be discussed.

TH3.1 Novel Non-equilibrium Phenomena in Quantum Fluids of Light

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Driven-dissipative quantum fluids of light, experimentally realised in for example semiconductor microcavities, circuit or cavity QED systems, provide a unique testbed to explore new non-equilibrium quantum phenomena. I will review recent progress in this field. In particular, we show that polariton quantum fluid can exhibit a non-equilibrium order, where superfluidity is accompanied by stretched exponential decay of correlations [1]. This celebrated Kardar-Parisi-Zhang (KPZ) phase has not been achieved before in any system in 2D, and even 1D realisations have not been conclusive. I will then discuss how these systems can undergo other unconventional phase transitions and orders [2], and display flow properties connected but distinct from conventional superfluidity. Finally, when placed in strained honeycomb lattice potentials, polariton fluids can condense into a rotating state, the lowest Landau level, forming a vortex array and spontaneously breaking time reversal symmetry [3]. Describing strong quantum correlations in open systems with drive and dissipation, especially in two dimensions, is a numerical challenge. I will briefly present our attempts at developing suitable methods, based on stochastic and tensor network approaches [4].

[1] A. Zamora et al., PRX 7, 041006 (2017); PRL 125, 265701 (2020); A. Ferrier et al., PRB 105, 205301 (2022)
[2] G. Dagvadorj et al., PRL 130, 136001 (2023); PRB 104, 165301 (2021)
[3] C. Lledo et al., SciPost 12, 068 (2022)
[4] C. Mc Keever et al., PRX 11, 021035 (2021); P. Deuar et al., PRX Quantum, 2, 010319 (2021)

TH3.2 Bose-Einstein condensation of excitons in a bulk semiconductor at sub-Kelvin temperatures

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Excitons are bound states of photoexcited electrons and holes in a semiconductor, resembling hydrogen atoms. Long-lived excitons in bulk cuprous oxide represent the most matter-like system where the coupling with the radiation field is very weak. The spontaneous Bose-Einstein condensation (BEC) of such quasi-particles formed in a many-electron system is nontrivial, and achieving experimental observation and investigating the properties of the condensate have been longstanding challenges. We achieved the lowest exciton temperature of approximately 100 mK through cooling the crystal using a dilution refrigerator and activating a cooling channel via the strain induced exciton-phonon interactions [1]. Successful observation of excitonic BEC [2] formed at the bottom of a accurately characterized three-dimensional harmonic trap using absorption imaging technique based on excitonic internal transitions [3] has been achieved.

In the presentation, along with the details of this experiment, we will introduce the historical perspective on why the sub-kelvin temperature regime became necessary and discuss the impact of exciton-exciton interactions in the condensate, as well as similarities and differences compared to BECs in conventional bosonic systems that are well understood.

[1] K. Yoshioka et al., Phys. Rev. B 88, 041201(R) (2013).
[2] Y. Morita et al., Nat. Commun. 13, 5388 (2022).
[3] K. Yoshioka et al., Phys. Rev. B 91, 195207 (2015).

TH3.3 Controlling Exciton-Polariton Vortices with Orbital Angular Momentum of Light

Deagwang Choi[1], Min Park[1], Byoung Yong Oh[1], Min Sik Kwon[1,2], Suk In Park[3], Sooseok Kang[3], Jin Dong Song[3], Yong-Hoon Cho[1,2], **Hyoungsoon Choi[1,2]**, Dogyun Ko[4,5], Meng Sun[4], Ivan G. Savenko[4,5]

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Despite their short lifetime in comparison to thermalization time, exciton-polaritons, quasiparticles formed inside a microcavity-quantum-well structure, are found to condense into their ground state, much like a Bose-Einstein condensate (BEC). Whether one can call such exciton-polariton condensate, an intrinsically non-equilibrium condensate, a BEC is debatable, but they do reveal unique properties of a superfluid including formation of quantized vortices. In this talk, I will describe a relatively simple technique for creating these quantized vortices in exciton-polariton condensate [1] and show time resolved dynamics of the vortex formation and extinction [2]. The observed effect is well-described by the driven-dissipative Gross-Pitaevskii equation coupled with pumping reservoirs.

[1] M. -S. Kwon and B. Y. Oh et al., Phys. Rev. Lett. 122, 045302 (2019).
[2] D. Choi and M. Park et al., Phys. Rev. B 105, L060502 (2022).

TH4.1 Non-linear Dynamics of the Trapped Quantum Vortex in Superfluid ^{4}He.

Sergey Kafanov[1], Amy Lester[1], Lev Melnikovsky[2], Nathaniel Morisson[1], Filip Novotny[3], Searbhan O Peatain[1], David Schmoranzer[3], Viktor Tsepelin[1]

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[2]Department of Chemistry and Materials Science, Weizmann Institute of Science, Rehovot, Israel,
[3]Department of Low Temperature Physics, Charles University, Prague, Czech Republic

Nanomechanical resonators have recently been studied as high-sensitivity probes of fluid dynamics in superfluid helium. When turbulence is introduced to such a system, quantum vortices may form and become trapped by the resonator, either completely surrounding the oscillating beam (a fully trapped vortex) or surrounding only part of it (a partially trapped vortex). Fully trapped vortices have been studied using the model of linear harmonic oscillator behaviour with great success. However, in the presence of a partially trapped vortex, the oscillators have been found to behave non-linearly. We analysed the non-linear response of a resonator submerged in helium-4 at 10 mK in the presence of a partially trapped vortex and present our findings.

TH4.2 Probing superfluid ^{3}He with a nanoelectromechanical oscillator

Vladimir Eltsov[1], Timo Kamppinen[1], Atso Ikäheimo[1], Jere Mäkinen[1], Šimon Midlik[2], David Schmoranzer[2], Matthew Doyle[3], Andrei Golov[3]

[1]Department of Applied Physics, Aalto University, Espoo, Finland
[2]Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic
[3]Department of Physics and Astronomy, University of Manchester, Manchester, UK

We have immersed a nanoelectromechanical oscillator into superfluid ^{3}He-B and used it to measure quasiparticle and vortex dynamics at temperatures below $0.2T_c$. The device has a goal-post shape with the legs and the paddle of approximately 100 μm length and 250 nm thickness, manufactured from bare aluminum over a window in a silicon substrate and driven and detected magnetomotively. The linear response of such devices in vacuum and when immersed in superfluid ^{4}He is well understood [1]. In ^{3}He-B, the device is found to be an excellent sensor of the quasiparticle density, exceeding sensitivity of a commercial tuning fork by a factor over 100. With rotation, we create quantized vortices and observe separate vortex attachment and detachment events in the device response. After spin-up or spin-down, the rate of events can be used to peek at the dynamics of individual vortices in collective vortex flows. We can also attach a single stable vortex to the device and probe three regimes of vortex dynamics: long Kelvin waves (KW) on a vortex hanging between the device and a pinning site 0.5 mm away, which gives KW resonance frequency of 0.3 Hz; short KW of wavelength comparable to the core size at the device's fundamental frequency of 16 kHz; excitation at frequencies relevant to core-bound fermions at the device's third harmonic of 40 kHz. The responses we observe are qualitatively different from those in superfluid ^{4}He, where vortices around a similar device are generated by a tuning fork.

[1] T. Kamppinen et al, Phys. Rev. B **107**, 014502 (2023).

TH4.3 Quantized vortices visualized using silicon nanoparticles in superfluid helium

Yosuke Minowa

Graduate school of engineering science, Osaka University, Osaka, Japan

The dynamics of quantized vortices in superfluid helium are revealed through visualization using silicon nanoparticles. The observed phenomena, such as vortex reconnection, are consistent with theoretical predictions. Silicon nanoparticles were prepared in situ using the laser ablation method. These nanoparticles possess distinct properties, such as high mass density and a large refractive index, which stand in contrast to standard tracer particles like hydrogen. Such unique properties enable us to expand the paradigm of quantized vortex research. As a promising example, we demonstrate that silicon nanoparticles can be optically trapped. Our results could pave the way for controlling and exciting quantized vortices using optical and other methods.

TH4.4 **Structure of Superfluid Suction Vortex**

Naoki Kakimoto, **Ken Obara**, Hideo Yano, Osamu Ishikawa

Department of Physics, Osaka Metropolitan University, Osaka, JAPAN

Although the suction vortex is the one of the most common vortices, its flow structure has not been fully understood. The main reasons for this are the experimental difficulty due to the very rapid flow change near the core. However, superfluid helium may help us better under- stand the suction vortex, because the flow in the superfluid helium can be characterized by the circulation measured by the first sound velocity, and the configuration of the quantized vortex lines can be measured with the second sound attenuation technique, as reported in our previous results [1]. In this presentation, we report the effectiveness of an ultrasound circulation meter using the correlation-based differential time-of-flight method. Using this technique, the accuracy for measuring the circulation was greatly improved; we found that the circulation was proportional to the rotation speed of the turbine, which can be interpreted by considering the transport and dissipation of total angular momentum in the fluid [2]. We also show the local vortex line density in the core region of the suction vortex as a function of the diameter of the drain hole.

[1] Phys. Rev. Fluids, **6**, 064802 (2021).
[2] J. Low Temp. Phys., **208**, 3795 (2022).

4.2 Poster Presentations: Thursday 10th August

TH5.1 **Influence of geometry on 2D turbulence in superfluid ^{4}He.**

Filip Novotný, Marek Talíř, Šimon Midlik, Emil Varga

Department of Low-Temperature Physics, Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic

Turbulence confined to 2D possesses unique properties, which are not observed in 3D. Probably the most striking contrast is the inverse cascade. The energy is transferred from small scales to large leading to the emergence of large coherent turbulence structures (vortices). In case of superfluid ^{4}He, 2D turbulence involves nearly point-like vortices, which under certain circumstances can be considered a realisation of the Onsager vortex gas [1]. The Onsager vortex gas was first experimentally observed in superfluid helium [2] and Bose-Einstein condensates [3] with a relatively small number of vortices. In this work, we study strongly turbulent flow in steady state using Helmholtz resonators based on previous experiments [4].

The Helmholtz resonator is a SiO2 chip with circular cavity 5 mm in diameter and two necks, which connect the cavity to the bulk ^{4}He. We used two different cavity heights: 500 nm and 2 μm and four different types of necks. For certain geometries, i.e. type of the neck, and sufficiently low temperatures, turbulence can exist in multiple stable states and stochastically switch between them. This behaviour of turbulent transition qualitatively changes with temperature with apparent critical behaviour, vanishing at sufficiently high temperatures. We investigated critical parameters in the temperature range between 1.35 K and 1.95 K and proposed brief theoretical explanation.

[1] L. Onsager, Nuovo Cim. 6 (S2), 279–287 (1949).
[2] Y. P. Sachkou, *et al.*, Science 366, 1480 (2019).
[3] G. Gauthier, *et al.*, Science 364, 1264 (2019).
[4] E. Varga, *et al.*, Phys. Rev. Lett. 125, 025301 (2020).

TH5.2 **Neural Network-Based Trial Function for Bosonic Systems: Application to ^{4}He Clusters**

William Freitas, S. A. Vitiello

Condensed Matter Physics, University of Campinas, Campinas, Brazil

A neural network-based trial function for clusters of ^4He_N, with N ranging from 2 to 14 atoms, has been developed to estimate various properties of these Bosonic systems. The trial function imposes translational symmetry and Bose-Einstein statistics, which are required by such systems. The resulting trial energies obtained using the variational Monte Carlo method are in excellent agreement with results obtained through the diffusion Monte Carlo method. The latter is only affected by statistical uncertainties. Density profiles and pair-atom contacts are also investigated. Various approaches for feeding input data into the network and stabilizing the optimization process are analyzed. An improved pseudopotential for the trial function is introduced by numerically solving the Schrödinger equation for an atom pair.

TH5.3 **Direct observations of pure ^{4}He and ^{3}He in ^{4}He mixture films using neutron reflection.**

Oleg Kirichek[1], Chris Lawson[1], Christy Kinane[1], Timothy Charlton[2], Andrew Caruana[1], Sean Langridge[1], Peter McClintock[3]

[1]ISIS Facility, STFC, UKRI, Didcot, UK
[2]Neutron Scattering Division, Oak Ridge National Lab, Oak Ridge, USA, [3]Department of Physics, Lancaster University, Lancaster, UK

Of the many quantum fluid systems superfluid helium films remain one of the most elusive for experimental investigation. We used neutron reflectometry to study liquid ^{4}He and 0.1% ^{3}He in ^{4}He mixture films. Thanks to the exceptional sensitivity and precision of this technique, we could observe and study 165 Å thick superfluid helium film formed on a silicon surface in temperature range from 170 mK to 1.5 K. In the temperature range of the experiment the change in reflectivity signal from ^{4}He film is insignificant. Addition of 0.1% of ^{3}He dramatically changes the film behaviour. At lowest temperature of 170 mK we observe a phase-separated ^{3}He -^{4}He mixture film with ^{3}He situated close to the surface. With the temperature increasing we witness a gradual dissolution of its ^{3}He top layer into ^{4}He. At around 300 mK whole helium film almost vanishes from the surface of the silicon substrate, leaving just clusters of mostly ^{3}He atoms. The observed anomaly in the film behaviour may be associated with phase transition. In the experiment we also found out an unexpected restoration of the layered structure at 1.5 K. Our results could be important for development of the powerful dilution refrigerators which, to significant extent, are limited by film flow effects.

TH5.4 **On the second layer of He-4 adsorbed on graphite: A shadow wave function approach.**

Vitor Zampronio Pedroso[1,2], Andrew Ho[1], Derek Lee[2]

[1]Department of Physics, Royal Holloway University of London, Egham, United Kingdom
[2]Department of Physics, Imperial College London, London, United Kingdom

The zero-temperature phase diagram of the second layer of He-4 adsorbed on graphite is investigated using a shadow wave function and the variational Monte Carlo method. We are interested in shedding some light on the long-debated discussion about the possible existence of a supersolid phase in such a system. In our simulations, the formation of commensurate structures and supersolids should be spontaneous if they exist. It is worth mentioning that the same wave function is used for liquids and solids in our formalism. We carefully examine static structure factors and radial distribution functions for each density analyzed to identify structures. Insights on the excitation spectrum and estimates of the superfluid density are also presented. Direct comparison with experiments and theory is given when applicable.

TH5.5 Dielectric and elastic anomalies in helium films

Fumiya Koike, Kohei Okamura, Yusuke Nago, **Keiya Shirahama**

Department of Physics, Keio University, Yokohama, Japan

^{4}He films adsorbed on a disordered substrate exhibit a quantum phase transition (QPT) from non-superfluid to superfluid states as the coverage exceeds the critical coverage. The non-superfluid state is a localized solid with an energy gap for excitation, and superfluidity emerges as the gap closes. This QPT picture was suggested by a heat capacity study [1] and established by our discovery of elastic anomalies [2]. The elastic anomaly is a useful tool for studying QPT.

Since the elastic anomaly resembles the dielectric properties found in hydrogen films in Vycor [3], we measured the dielectric properties of ^{4}He films on a nanoporous glass. We found that the dielectric properties are also anomalous at the same coverage and temperature as those at which the elastic anomaly occurs. The dielectric anomaly is characterized by a decrease in the dielectric constant with a peak in the dielectric loss. In particular, the dielectric constant and dielectric loss are reduced below those of the glass substrate itself at low temperatures where helium atoms are localized, i.e. effectively negative dielectricity and loss. This anomalous behavior is attributed to the strong influence of localized helium atoms on the tunneling properties of the two-level systems on the glass surface. Dielectric measurements can also be utilized to study QPT and superfluidity of helium films.

[1] R. H. Tait and J. D. Reppy, PRB 20, 997 (1979).
[2] T. Makiuchi et. al., PRB 79, 092506 (2009).
[3] A. Dertinger et al., PRB 55, 22 (1997).

TH5.6 Search for the Gas-Liquid Critical Point in ^{3}He Monolayer on Graphite

Atsuki Kumashita[1], Jun Usami[2], Hiroshi Fukuyama[2], Kazuma Mori[1], Yu Yamane[1], Akihiko Sumiyama[1], Akira Yamaguchi[1]

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[2]Cryogenic Research Center, The University of Tokyo, Tokyo, Japan

Helium films on a flat surface offer an ideal platform for studying two-dimensional (2D) quantum systems with tunable correlation. The question of whether 2D ^{3}He systems can undergo liquefaction at T=0 has long been a topic of fundamental interest. Unlike the previous theoretical predictions, the recent experiment [1] has reported ^{3}He monolayer on graphite are gas-liquid phase separated below 80 mK when particle densities are lower than 0.6-0.9 nm^{-2}. Subsequently, various sophisticated calculations (e.g. [2]) were made inspired by this experiment, but the present situation is still far from complete understanding. From the experimental viewpoint, it is important to confirm the existence of the gas-liquid critical point, which is expected to be there in 80-700 mK but not found yet, and to check possible roles of substrate imperfections on the reported phase separation. We have recently started new heat capacity measurements to observe the critical point directly, using a newly developed calorimeter [3] with a ZYX exfoliated graphite enclosed in a superconducting Nb container. This calorimeter has a sufficiently small addendum heat capacity in the relevant temperature range. Since ZYX has much less substrate imperfections than the previously used Grafoil [1], we should also be able to address the substrate effects. Details of the experimental setup and preliminary results on the second layer of ^{3}He will be discussed.

[1] D. Sato *et al.*, Phys. Rev. Lett. **109**, 235306 (2012).
[2] M. C. Gordillo and J. Boronat, Phys. Rev. B **94**, 165421 (2016).
[3] J. Usami *et al.*, J. Low Temp. Phys. **203**, 1 (2021).

TH5.7 **Spin diffusion of dilute ^{3}He fluid in ^{4}He-precoated 1D nanochannels**

Azimjon Temurjonov[1], Yuya Miyauchi[1], Yasuhiro Shimizu[1], Masayuki Itoh[1], Yoshiaki Kobayashi[1], Mitsunori Hieda[2], Nobuo Wada[1], **Taku Matsushita[1]**

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[2]College of Lib. Arts Sci., Tokyo Medical and Dental University, Ichikawa, Japan

To examine possibility of ^{3}He Tomonaga-Luttinger liquid (TLL), the fluid state of ^{3}He adsorbed in ^{4}He-precoated nanochannels of FSM a few nm in diameter have been investigated by heat capacities and ^{3}He NMR. At dilute ^{3}He densities (on the order of 0.01 atomic layers) where the azimuthal motion of all ^{3}He in 1D channels is the ground state at zero temperature, the quantum-mechanically genuine 1D fluid of ^{3}He adatoms is realized at low temperatures. The experimental 1D condition for the temperature and ^{3}He density can be 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 in the genuine 1D state of dilute ^{3}He and agrees with that expected for possible TLL states. On the other hand, 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, and the range of ^{3}He diffusive motion in the NMR time scale compared with the 1D channel length. To further investigate the motional state of 1D ^{3}He in nanochannels, NMR experiments to observe spin diffusion of ^{3}He are in progress using stimulated echoes. We show preliminary results at relatively high temperatures for nondegnerate fluid.

[1] T. Matsushita et al., Phys. Rev. B **103**, L241403 (2021).

TH5.8 **Experimental study of ^{3}He confined within a nematic carbon nanotube array**

Jere Mäkinen, Vladimir Eltsov

Aalto University

We study the properties of pure ^{3}He confined within a VANTA (vertically aligned nanotube array) sample with nanotube diameter and density comparable to previous nafen samples. Our experimental findings indicate only a minor suppression of the superfluid transition temperature with respect to bulk transition at all pressures in combination with Curie-Weiss-like behavior of the solid ^{3}He layer covering the surfaces of the carbon nanotubes. The extracted Curie temperatures are much lower than in bulk samples, at or below the ~100 μK range, possibly suggesting a difference in the structure of the covering solid layer. Moreover, the nuclear magnetic resonance spectrum is split into three distinct peaks at low temperatures, with both positive and negative frequency shifts. At pressures below 10 bar both the observed total susceptibility and frequency shift of the feature with the most positive frequency shift agree with a model assuming that the total susceptibility is a simple sum on the liquid and solid contributions, while the frequency shift is their reduced shift. At pressures exceeding 15 bar the model fails in both respects, suggesting a possible magnetic ordering transition in the solid layer.

TH5.9 Three dimensional Ginzburg-Landau calculations of vortex structures in ^{3}He-B

Riku Rantanen, Vladimir Eltsov

Department of Applied Physics, Aalto University, Espoo, Finland

The spin-triplet p-wave superfluid helium-3 is characterized by an order parameter that is a 3×3 complex matrix. Due to the structure of the order parameter, the symmetries of the normal fluid can be spontaneously broken in many different ways, leading to multiple stable superfluid phases and a rich variety of topological structures such as quantized vortices. In the B phase of ^{3}He, there are two types of stable single-quantum mass vortices that have been observed: the axisymmetric vortex with an A phase core found at high temperatures and pressures, and an asymmetric vortex where the core has split into two halves connected by a domain wall, breaking the rotational symmetry.

The asymmetric vortex allows for further symmetry breaking of the translational symmetry in the direction along the vortex by twisting the two half-cores around each other. When such a vortex passes through the Bose-Einstein condensate of magnon quasiparticles created in the liquid, the coherent spin precession of the condensate causes a slow drift of the half-core's orientation, resulting in twisting. We present calculations of the free energy of the twisted and untwisted vortex states at different points of the phase diagram. The Ginzburg-Landau energy minimization is performed on an unstructured tetrahedral mesh, which allows for simulation of complicated three-dimensional geometries, including the possibility of vortex pinning sites. The calculation takes advantage of the great parallelization potential of modern graphics cards in order to handle the increased number of mesh points in three dimensions.

TH5.10 Nanofluidic Device for Experimental Realisation of the Polar Phase of Superfluid ^{3}He

Daksh Malhotra, Alexander Shook, John Davis

Department of Physics, University of Alberta, Edmonton, Canada

Superfluid ^{3}He under strong confinement has attracted significant interest due to observations of novel phases not observed in the bulk [1, 2, 3]. Interactions with confining surfaces can cause pair-breaking and alter the free energy landscape of possible phases. Free energy calculations have demonstrated that in a pseudo-1D confinement, realised using nano-scale channels, the polar phase [4] - with a line node in its gap structure - can be stabilised [5]. We have designed nanofluidic Helmholtz resonators using photolithography and electron beam lithography to provide confinement on the order of a few coherence lengths. These fourth-sound resonators consist of two basins connected by a nanometer-scale square channel and will be immersed in superfluid ^{3}He. New insights into the polar phase can be expected in this highly-controlled geometry, as compared with the confinement provided by aerogels. It may be possible to use these devices to explore the rich vortex structure including half-quantum vortices of the polar phase and other phases stabilised by confinement [5].

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TH5.11 Analytical expression of Green's function for superfluid ^{3}He B phase with surface bound state under magnetic field

Yasumasa Tsutsumi

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There are Majorana fermions at a surface of the superfluid ^{3}He B phase (^{3}He-B). The surface bound state has an energy gap under magnetic field perpendicular to the surface. The energy gap will be detected by the ion mobility below the free surface of ^{3}He-B. The mobility of ions is determined by the momentum transfer from the ^{3}He quasiparticles to the ions by the scattering. The scattering process is described by the Lippman-Schwinger equation including the Green's function as a propagator. In advance of the calculation of the ion mobility, an analytical expression of the Green's function for ^{3}He-B under magnetic field perpendicular to the free surface has been discussed in this presentation. Although we can calculate the Green's function numerically, the numerical form of the Green's function is inconvenient to solve the Lippman-Schwinger equation.

The analytical expression of the Green's function consists of the surface bound state and the continuum state above the superfluid gap. The Green's function for the continuum state is obtained from the Green's function in the bulk ^{3}He-B under the magnetic field. The wave function and the energy dispersion of the surface bound state give the Green's function for the surface bound state. The hybridization of the surface bound state and the continuum state by the magnetic field has been also discussed in the presentation.

TH5.12 QUEST-DMC: Early-Universe phase transitions in nanoconfined superfluid helium-3

Petri Heikkinen[1], Lev Levitin[1], Nathan Eng[1], Xavier Rojas[1], Mark Hindmarsh[2,3], Kuang Zhang[2,3], Stephan Huber[2], Jeevak Parpia[4], Andrew Casey[1], John Saunders[1]

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[4]Department of Physics, Cornell University, Ithaca, USA

The mechanism of first-order phase transition between ^{3}He-A and ^{3}He-B is still an open question after decades of studying it. Understanding whether this phase transition can be triggered by intrinsic means would provide insight into the type of phase transitions which took place in the early Universe, crucial for predicting the signatures of associated gravitational waves. However, the homogeneous nucleation theory – the leading theory for cosmological phase transitions – predicts lifetimes of metastable supercooled A phase longer than the age of the Universe. Various competing, sometimes complementary, alternative models have been developed, ranging from cosmic-ray-induced nucleation (with or without the aid of rough surfaces and textural singularities) to resonant tunnelling phenomenon.

In this work we present our modern approach to the phase-nucleation puzzle and report the first experimental SQUID-NMR results. We have aimed to cancel the effect of rough surfaces and to minimise the possibly volume-dependent effect of external radiation: (1) We confine the superfluid in a nanofabricated atomically smooth silicon-based sample container, fully isolated from the rough heat exchanger and the fill line by 75 nm high regions that will only support ^{3}He-A or normal fluid, depending on the quasiparticle scattering boundary condition. (2) We have five isolated 6.8 µm deep chambers within single experimental cell to greatly increase the occurrence of nucleation in case of a stochastic process, each having a different size but all several orders of magnitude smaller in volume than any earlier experiment of the same type.

TH5.13 **Tuning the phase diagram of superfluid ^{3}He with electric field**

Lev Levitin

Royal Holloway, University of London, Egham, Surrey, UK

Superfluid ^{3}He inside a thin parallel-plate capacitor is considered within Ginzburg-Landau theory. The electric field induces polar distortion of the superfluid order parameter via the electric dipole interactions, which competes with the planar distortion due to confinement inside the capacitor. A rich phase diagram emerges, containing the A, polar and distorted A and B phases. Stabilizing the polar phase with electric field is found to be experimentally challenging but feasible, opening the prospects of studying and manipulating half-quantum vortices in the absence of disorder.

TH5.14 **Quasiparticle transport in a two-dimensional boundary superfluid**

S Autti[1], R P Haley[1], A Jennings[1,2], G R Pickett[1], M Poole[1], R Schanen[1], A A Soldatov[3], V Tsepelin[1], J Vonka[1,4], V V Zavjalov[1], D E Zmeev[1]

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[2]RIKEN Center for Quantum Computing, RIKEN, Wako, Japan
[3]Paul Scherrer Institute, Villigen, Switzerland
[4]P.L. Kapitza Institute for Physical Problems of RAS, Moscow, Russia

The bulk B phase of superfluid ^{3}He is bounded by a two-dimensional quantum well at the boundaries of the container, where creating quasiparticles requires much less energy. Here we carry out experiments where we create a non-equilibrium state within the quantum well and show that the induced quasiparticle currents flow diffusively in the two-dimensional system. We conclude that bulk is wrapped by an independent two-dimensional superfluid that exclusively interacts with mechanical probes, only providing access to the bulk superfluid if given a sudden burst of energy. That is, superfluid ^{3}He at the lowest temperatures and across orders of magnitude of applied energy is thermo-mechanically two dimensional. Our work opens this two-dimensional quantum condensate and the interface it forms between the observer and the bulk superfluid for exploration and provides the possibility of creating two-dimensional condensates of arbitrary topology.

TH5.15 Thermal transport between and within surface layers of superfluid ^{3}He-B

Vladislav Zavjalov, Samuli Autti, Dmitry Zmeev

Department of Physics, Lancaster University, Lancaster, United Kingdom

We study a superfluid ^{3}He-B sample thermally connected with a copper nuclear demagnetization stage via silver sinter with large interface area (about 50 m^2). An important role in this system is played by the surface which contains a layer of solid paramagnetic helium and a layer of superfluid with suppressed order parameter. These systems have noticeable heat capacities and can be distinguished due to different thermal transport between them: for example, bulk ^{3}He thermalises with surface systems with a time constant of about 1s, while thermalisation time of the surface with the nuclear stage can reach a few hours, depending on the magnetic field. Our experiments show that the paramagnetic layer of solid helium works as an effective coolant in demagnetization process. We also show that thermal transport along the surface is comparable with bulk thermal conductivity and becomes dominant in a geometry where propagation of ballistic quasiparticles in bulk ^{3}He-B is suppressed.

TH5.16 Scaling the edge of superfluid ^{3}He-B

Luke Whitehead, Samuli Autti, Richard Haley, Roch Schanen, Vladislav Zavjalov, Dmitry Zmeev, George Pickett

Department of Physics, Lancaster University, Lancaster, United Kingdom

At container boundaries, the energy required to create quasiparticles in ^{3}He-B is greatly suppressed, resulting in a two-dimensional quantum well surrounding the bulk, but accessing this potentially interesting edge system is difficult. We use mechanical probes to reveal the dynamics of this system. In our experiments we can accelerate the probe together with the edge system with respect to the fully-gapped bulk. This acceleration results in the ejection of the most energetic surface quasiparticles into the bulk, where they can be readily detected and characterised. We show that in the low temperature limit, the B-phase of helium-3 consists of two separate systems - the bulk, and the thermo-mechanically isolated edge states, where quasiparticles travel diffusively through the well. Our calculations show that the dynamics in the edge system strongly depends on its size. We discuss future experiments which will utilise the size of the mechanical probe as the parameter of the edge system. We hope that these experiments will help us to further our understanding of dynamics and coherence in this fascinating system.

TH5.17 **Experiments with hydrogen atoms at ultra-low energies**

Aleksei Semakin, Otto Hanski, Janne Ahokas, Sergey Vasiliev

Wihuri Physical Laboratory, Department of Physics and Astronomy, University of Turku, Turku, Finland

We present recent progress towards experiments with hydrogen atoms at ultra-low temperatures, probing the ultra-low energy domain with the lightest and simplest of neutral atoms, which has served as a test probe of the fundamentals of physics throughout the era of modern physics. This work is part of an international collaboration GRASIAN [1].

We will accumulate and evaporatively cool H gas below 1mK.Then ultra-slow atoms will be released from the trap onto a perfectly flat surface of superfluid helium, from which their quantum reflection will lead to formation of gravitational quantum states (GQS) in the potential well created by the surface and Earth gravity. Precise measurements of the GQS energies will improve constraints on the existence of the unknown short-range forces between atoms and materials surface. Precision optical and microwave spectroscopy will be performed at the conditions when the atomic velocity related effects are eliminated, e.g. improving the accuracy of the 1S-2S interval. Our methods and results will be useful for experiments with antihydrogen pursued at CERN.

We report on the first experiments where we have demonstrated magnetic capture and confinement of H gas at a temperature below 50 mK in our Ioffe-Pritchard trap [2]. Measuring the heat released in recombination of atoms, we found that loading atomic flux of over $3 \cdot 10^{13}$ atoms/s reaches the SC and $\sim 2 \cdot 10^{14}$ atoms are trapped at a temperature of ~50 mK. At the next stage,the magnetic trap system will be modified to reach the sub-mK temperature and optical components necessary for the 1S-2S spectroscopy will be assembled.

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TH5.18 **Studies of the structures of nitrogen-neon nanoclusters immersed into superfluid helium-4**

Cameron Wetzel, Oleksandr Korostyshevski, David Lee, Vladimir Khmelenko

Department of Physics and Astronomy, Texas A&M University, College Station, United States

We studied the electron spin resonance (ESR) spectra of nitrogen atoms stabilized in nitrogen-neon nanoclusters immersed in superfluid ^{4}He. The nanoclusters were formed during the condensation of the products of the discharge in N_2-Ne-He gas mixtures into bulk superfluid ^{4}He at temperature 1.5 K. We studied nanoclusters formed by injection of gas mixtures with different ratios of heavy impurities in the helium N_2/Ne from 0.01% to 50%. The analysis of the ESR spectra of nitrogen atoms stabilized in nitrogen-neon nanoclusters provides important information on their surroundings and the structure of the nanoclusters. At small ratios of N_2/Ne all of the stabilized nitrogen atoms were surrounded by Ne atoms in nanoclusters. Increasing the N_2/Ne ratio led to the preferential stabilization of N atoms on the surfaces of N_2 nanoclusters. An influence of the power of the discharge on the structure of the nanoclusters was also studied. Annealing of the collection of the nanoclusters in the temperature range 1.3-10 K resulted in substantial changes in the structure of the nanoclusters.

TH5.19 Quantum Droplets in Imbalanced Atomic Mixtures

Thomas Flynn, Luca Parisi, Thomas Billam, Nick Parker

School of Mathematics, Statistics and Physics, Newcastle University, Newcastle upon Tyne, United Kingdom

Quantum droplets are a quantum analogue to classical fluid droplets in that they are self-bound and display liquid-like properties --- such as incompressibility and surface tension --- though their stability is the result of quantum fluctuations. One of the major systems for observing quantum droplets is two-component Bose gases. Two-component droplets are typically considered to be balanced, having a fixed ratio between the densities of the two components. The work presented here goes beyond this fixed density ratio by investigating spherical droplets in imbalanced mixtures. With increasing imbalance, the droplet is able to lower its energy up to a limit, at which point the droplet becomes saturated with the atoms of the majority component and any further atoms added to this component cannot bind to the droplet. Analysing the breathing mode dynamics of imbalanced droplets indicates that the droplet can emit particles, as in balanced mixtures, but the imbalance leads to an intricate superposition of multiple simultaneously decaying collective oscillations. Droplets are self-bound and hence can be observed both in free space and within confining trapping potentials, as is more relevant for most experimental protocols. Thus, the free space analysis of this work is extended to explore the modifications an external potential has on the imbalanced droplet ground states and dynamics.

TH5.20 Collective-mode excitations and nonlinear dynamics in an attractive Bose-Bose mixture

Gary Liu, Nick Proukakis

School of Mathematics, Statistics and Physics, Newcastle University, Herschel Building, Newcastle upon Tyne, NE1 7RU, UK

Motivated by the recent Cs-Yb condensate experiment [Phys. Rev. Research **3**, 033096 (2021)], we numerically investigate the collective-mode excitation of a two-component Bose-Einstein condensate with attractive inter-species interaction via the Bogoliubov-de-Gennes approach in a fully 3D calculation to analyze the nonlinear dynamics in the experiment. The dipole modes, excited in the experimental setup, are identified by the quasi-particle projection method with success in explaining the oscillation frequencies and the corresponding motions actually exhibit the coupling of complicated multi-type motions. Hence the multi-mode nonlinear coupling yields the decay of dipole motion while the other types of motions are excited, such as the dipole and breathing modes in one of the components along the non-excited axes. Furthermore, an effective two-mode model is proposed to investigate the roles of kicking amplitude, particle numbers and inter-species interaction in the dipole modes with the knowledge of the oscillation frequencies.

TH5.21 Machine learning methods in computational physics

Jack Griffiths

Department of Physics, Durham University, Durham, United Kingdom

In this presentation, we explore the emerging intersection of machine learning and physics, and how it applies to our field of quantum fluids. We introduce prototype machine learning models which can—within fractions of a second—predict the temperature and chemical potential of Bose gases with a thermal component. We explore the computational requirements for training the full model on Bose gases of different species and traps using only atomic density profiles (which are experimentally accessible).

TH5.22 Vacancion transport of charges in solid bcc and hcp helium

Andrei Golov[1], Victor Efimov[2], Alexander Levchenko[2], Leonid Mezhov-Deglin[2]

[1]Department of Physics and Astronomy, University of Manchester, Manchester, UK
[2]Institute of Solid State Physics, Chernogolovka, Russia

We review measurements [1-3] of the drift velocity of positive and negative ions through bcc and hcp helium and interpret them within the framework of the theory by Andreev-Meierovich-Savishchev [4-6] of the inelastic scattering of long-wavelength vacancions off the ion. Depending on the ion species, density of solid helium and, for hcp ^{4}He, orientation of the driving field E, the low-field mobility is governed by the scattering of either one or two vacancions. For positive ions in hcp ^{4}He travelling along the C_6 axis, a substantial enhancement of the drift velocity is observed at temperatures below ~ 1 K in electric field below ~ 4×10^4 V/cm; this could be related to a phonon-free one-vacancion process, where the finite width of the vacancion energy band, Δ ~ 5-10 K, restricts it to fields such that $e\mathbf{E}\mathbf{b} < \Delta$, where $|\mathbf{b}|$ ~ 1 Å is a vector connecting equivalent positions of the ion in hcp lattice.

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[3] O. A. Andreeva, K. O. Keshishev and D. I. Kholin, Pis'ma Zh. Eksp. Teor. Fiz. **65**, 90 (1997).
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[6] A. F. Andreev and A. D. Savishchev, Zh. Exp. Teor. Fiz. **119**, 403 (2001).

TH5.23 The ^{4}He supersolid in two dimensions: a status report

Jan Nyeki, Brian Cowan, John Saunders

Department of Physics, Royal Holloway University of London, Egham, United Kingdom

We have identified the second layer of ^{4}He adsorbed on graphite as a two dimensional supersolid, and proposed that it is a non-Abelian quantum state with intertwined superfluid and density wave (DW) order [1-3]. These measurements were performed down to 2 mK, necessary to track the evolution of the supersolid response over the full density range of second layer solid. Torsional oscillator signatures have been confirmed to be frequency independent over a limited range, in studies to 20 mK, strongly supporting the identification of a supersolid [4]. Theoretical work [5] finds supersolid response at the 7/12 superlattice coverage. To confirm the existence of DW order we have doped the second layer with small concentrations of ^{3}He, which behave as delocalised quasiparticles subject to strain mediated interactions. The ^{3}He NMR response from a fixed amount of ^{3}He impurities clearly tracks the onset of solid (DW order). We tune through a pronounced anomaly in spin lattice relaxation time at the 7/12 coverage, indicating strong localisation of ^{3}He. The different regimes of scaling behaviour of the supersolid response are clearly correlated with the evolution of the structure.

[1] Jan Nyeki et al., Nature Physics **13**, 455 (2017)
[2] Jan Nyeki et al., J. Low Temp. Phys.**187,** 475 (2017)
[3] John Saunders et al., J. Low Temp. Phys. **201**, 615 (2020)
[4] Jaewon Choi et al., Phys. Rev. Lett. **127**, 135301 (2021)
[5] M. C. Gordillo and J. Boronat, Phys. Rev. Lett. **124**, 205301 (2020)

4.3 Invited Oral Presentations: Friday 11th August

FR1.1 **Finite-size effects and nonlinear behaviour in strongly confined superfluid helium.**

Emil Varga

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When confined to small sizes, condensed matter systems generally exhibit altered behaviour compared to bulk cases. Superfluid ^{4}He (He II) is a popular model system for these finite-size effects, since, due to lack of viscosity, He II can fill narrow channels and the superfluid order parameter (the macroscopic wave function) does not couple to any physical fields which might be exerted by the substrate (e.g., magnetic ordering) [1].

We study finite-size effects in He II using nanofluidic Helmholtz resonators [2,3] with strongly confined sub-μm quasi-2D channels. We show that the finite-size suppression of superfluid density in ^{4}He confined strongly to 2D channels is dominated by a surface-bound roton-like excitation with an energy gap of approximately 5 K. Close to the bulk phase transition, we observe for the first time the Kosterlitz-Thouless phase transition at increased pressure in a pure ^{4}He system. Additionally, for sufficiently high velocities, the two-dimensional flows exhibit nonlinear dissipation likely related to the development of turbulence. The observed nonlinear behaviour is influenced strongly by temperature (i.e., the dissipation suffered by the vortices moving in the flow) and geometry. Several types of critical phenomena (controlled by either temperature or velocity) are observed, likely related to vortex depinning and development of inverse cascade in the two-dimensional turbulence.

[1] F. M. Gasparini et al., Rev. Mod. Phys. 80, 1009 (2008). [2] E. Varga et al., Phys. Rev. Lett. 129, 145301 (2022). [3] E. Varga et al., Phys. Rev. Lett. 125, 025301 (2020)

FR1.2 **Structural study of two-dimensional helium on graphite with synchrotron radiation X-rays**

Akira Yamaguchi[1], Hiroo Tajiri[2], Atsuki Kumashita[1], Jun Usami[3], Yu Yamane[1], Akihiko Sumiyama[1], Tomoki Minoguchi[4], Masaru Suzuki[5], Yoshiharu Sakurai[2], Hiroshi Fukuyama[6]

[1]Graduate School of Science, University of Hyogo, Hyogo, Japan, [2], Japan Synchrotron Radiation Research Institute, Hyogo, Japan, [3], National Institute of Advanced Industrial Science and Technology, Ibaraki, Japan, [4]Institute of Physics, The University of Tokyo, Tokyo, Japan, [5]Department of Engineering Science, University of Electro-Communications, Tokyo, Japan, [6]Cryogenic Research Center, The University of Tokyo, Tokyo, Japan

Surface X-ray diffraction (SXRD) using a synchrotron radiation facility is a promising and powerful technique for investigating surface structures of various materials including adsorbates, thin films, and relaxed layers [1]. Recently, we started applying SXRD to the research of helium atomic layers adsorbed on graphite, which are an ideal test ground for two-dimensional quantum systems. A home-made low-temperature cryostat based on a Gifford-McMahon cryocooler with a 1 K pot was developed and was installed in the existing ultra-high vacuum system at the synchrotron radiation facility, SPring-8. Using this cooling system, helium monolayers adsorbed on a highly oriented pyrolytic graphite (HOPG) have been studied by SXRD with a reflection geometry at T=1.4 K. The experiments clearly revealed the structure of a sub-monolayer helium film perpendicular to the HOPG surface using crystal truncation rod (CTR) scatterings [2,3], which is sensitive to the height of an adsorbed layer from a substrate surface. To reveal in-plane structures of the helium films, we are currently working on SXRD in a transmission geometry. Preliminary experimental attempts show that it will be possible to detect superlattice reflections from helium thin-films on an atomically-flat graphite surface. This work was supported in-part by the JSPS KAKENHI Grant Numbers 22H03883 and 20H05621 and with the approval of the RIKEN Proposal Number 20220087.

[1] H. Tajiri, Jpn. J. Appl. Phys. 59, 020503 (2020). [2] A. Yamaguchi, et al., J. Low Temp. Phys. 208, 441 (2022). [3] A. Kumashita, et al., arXiv:2210.04411 (to be published in JPS Conf. Proc).

FR1.3 Atomically Thin Superfluid and Solid Phases for Atoms on Strained Graphene

Adrian Del Maestro[1], Sang Wook Kim[2], Valeri Kotov[2]

[1]Physics & Astronomy, University of Tennessee, Knoxville, USA, [2]Physics, University of Vermont, Burlington, USA

Atoms deposited on atomically thin substrates are a playground for exotic quantum many-body physics due to the highly tunable, atomic-scale nature of the interaction potentials. The ability to engineer strong interparticle interactions can lead to the emergence of collective states of matter, not possible in the context of dilute atomic gases confined in optical lattices. While it is known that the first layer of adsorbed helium on graphene is permanently locked into a solid phase, we motivate with a physically intuitive mean field calculation and confirm with quantum Monte Carlo simulations, that simple isotropic graphene lattice expansion effectively unlocks a large variety of two-dimensional ordered commensurate, incommensurate, cluster atomic solid, and superfluid states for adsorbed atoms. It is especially significant that an atomically thin superfluid phase of matter emerges under experimentally feasible strain values, with potentially supersolid phases in close proximity on the phase diagram.

FR1.4 A Novel Experimental Platform for Unveiling Quantum Phenomena in Helium Films Adsorbed on Graphite

Yongmin Kang[1,2], **Eunseong Kim**[1,2]

[1]Department of Physics, KAIST, Daejeon, South Korea
[2]Graduate School of Quantum Science and Technology, KAIST, Daejeon, South Korea

Graphite has been widely utilized as an ideal substrate to study the unique properties of two-dimensional films of quantum fluids, including ^{4}He films which exhibit intriguing nonclassical phases such as registered solid and superfluid phases. However, the quantum behaviors of helium on graphite have not been fully understood due to limitations in sensitivity caused by unwanted tortuosity in conventional graphite substrates. To address this, we propose a cavity optomechanical system as a new experimental platform to investigate the properties of helium films on graphite with enhanced sensitivity.

In our approach, the mass and stiffness changes in the helium film can be directly reflected in the responses of a graphene mechanical resonator. The mechanical motion of the graphene resonator is monitored through a capacitively coupled superconducting coplanar waveguide cavity using optomechanically induced transparency. Here, we present the progress in the fabrication of an on-chip cavity optomechanical system, which offers highly sensitive measurements for studying the 2D nature of both quantum and classical gases. We expect that this measurement scheme can be utilized as an ultimate platform to study the 2D nature of quantum and classical gases

FR2.1 Searching for ultralight dark matter using superfluid helium optomechanical systems

Swati Singh[1], Marvin Hirschel[2], Ryan Petery[1], John Davis[2]

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[2]Department of Physics, University of Alberta, Edmonton, Canada

The coupling of normal, Standard Model matter with dark matter sometimes manifests itself as a mechanical effect: strain, recoil kicks, or acceleration. Following a review of the expected mechanical signature, I will discuss the feasibility of searching for ultralight dark matter using optomechanical systems, highlighting the unique advantages of superfluid-helium-based optomechanical systems. I will show that current mechanical systems have the sensitivity to set new constraints on dark matter composed of ultralight scalar and vector particles. Finally, I will briefly overview the promise of quantum noise limited detectors in the search for beyond the standard model physics.

FR2.2 HeRALD: Measurement of dark matter scattering events in superfluid helium-4 through quantum evaporation and energy-resolved single photon detection

Daniel McKinsey[1,2]

[1]Physics, University of California, Berkeley, Berkeley, CA, USA
[2]Physics, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

We are surrounded by dark matter particles, yet their masses and non-gravitational interaction properties remain unknown. Discovery of the fundamental nature of dark matter particles would revolutionize particle physics and cosmology, opening new lines of scientific inquiry. The TESSERACT project is aimed at the development of experimental methods to probe dark matter masses down to 10 MeV in the near term, with upgrade paths to sub-MeV masses. TESSERACT is currently in a preparatory R&D phase focused on pushing Transition Edge Sensor recoil energy thresholds into the sub-eV regime, and then applying this next generation of sensors to a variety of well-motivated target materials.

The HeRALD portion of the effort employs a novel active target material: superfluid ^4He. Helium's nuclear recoil sensitivity benefits from a low-mass target nucleus, a unique quantum evaporation phonon readout method, and a minimum of intrinsic background sources due to its extreme radiopurity and coalescence into a macroscopic ground state. I will describe the motivation behind sub-GeV dark matter searches, the HeRALD technique, and recent experimental progress toward realization of dark matter detectors using superfluid ^4He.

FR2.3 QUEST-DMC: Low Mass Dark Matter Search with Superfluid Helium-3

Elizabeth Leason

Physics, Royal Holloway University of London, Egham, United Kingdom

There is evidence on range of astrophysical scales, that most of the matter in the universe consists of non-baryonic dark matter. WIMP (Weakly Interacting Massive Particle) dark matter in the 10-100GeV mass range has been strongly constrained, however there are well motivated models at lower masses.

The QUEST-DMC experiment aims to utilise superfluid He-3 as a collision target probe sub-GeV dark matter parameter space. Target cells instrumented with nanomechanical resonators, can be used to detect thermal energy deposited by dark matter interactions. Readout of the resonators using SQUIDs will allow very low energy thresholds to be achieved.

Here, work will be presented on the optimisation and projected sensitivity of the experiment, plus development of the key enabling technologies. This includes background simulations and radioassays, plus modelling of the detector response and readout noise. The resulting projected sensitivity of the experiment to dark matter models will be presented. Recent developments in bolometric measurements and SQUID readout will also be shown.

FR3.1 Characterization and Universal Scaling Properties of a Turbulent Atomic Superfluid

Vanderlei S Bagnato

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In this presentation we will combine many of the experiments performed in Brazil relating to the production and characterization of a Bose Condensate of Rb atoms, driven far from equilibrium. Excitation of the trapped BEC can be done through a combination of fields that promote time distortion of the trapping potential. These excitations can evolve over time, promoting energy migration from the largest to the smallest scales in a process called cascade. We perform temporal excitations that consist of deformation and slight rotation of the potential, causing the system to evolve to a turbulent regime. Simulations demonstrated generation of solitons, vortices and waves in the sample. Using time of flight techniques, we measure the moment distribution, $n(k, t)$ and from it we obtain the energy spectrum $E\,(k, t)$. This makes it possible to identify the inertial regions, where $E\,(k, t)$ is clearly dependent on the power law (inertial region) characteristic of turbulent regime, and to measure the energy flow migrating between the scales and their preservation from the absence of dissipation. Finally, the temporal evolution of the moment distribution allows to verify the presence of a space-time scalability, which indicate the presence of a class of universality in the phenomenon. The problem is investigated on the basis of the theory of the existence of non-thermal fixed points in the system and a discussion around these aspects is offered.

This work received support from FAPESP- program CEPID, CNPq and CAPES, all Brazilian agencies and had the participation of L. Madeira, A. Garcia-Orosco, P. Castilho, M. Moreno, L. Machado, G. Telles, H A. J. Middleton-Spencer (visiting student) A. and P.E.S. Tavares.

FR3.2 Visualization study of the law of wall in superfluid helium-4

Mikai Hulse[1,2], Hamid Sanavandi[1,2], Parmit Virdi[1,2], Yang Zhang[1,3], Louis Cattafesta[1,3], **Wei Guo[1,2]**

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The "law of the wall" is a fundamental principle that describes the logarithmic form taken by the mean velocity of a turbulent flow near a solid wall at high Reynolds numbers. However, this law may not apply to superfluid helium-4 (He II), which is composed of two fully miscible components: an inviscid superfluid and a viscous normal fluid. Although previous research has suggested that a mutual friction can couple the two fluids in mechanically generated flows, it is unclear whether this coupling is effective in the very thin boundary layer where an extremely strong velocity gradient exists. If the velocities of the two fluids are mismatched, the mutual friction may alter the classical law of the wall to a new form. Understanding the near-wall velocity profile in He II expands our knowledge of turbulence and provides a basis for theoretically modeling the friction factor in He II pipe flows, which is necessary in the design of He II-cooled particle accelerators and superconducting magnets. Here, we present a flow visualization study of the near-wall velocity profile in He II pipe flows with Reynolds numbers exceeding 10^6. We adopt our molecular tagging velocimetry technique to track the motion of a thin molecular tracer line created perpendicular to the pipe wall. By analyzing the image data, we demonstrate for the first time that the log-law near-wall velocity profile indeed exists in He II, albeit with a Kármán's constant that is only half the value found in classical fluids.

FR3.3 2D Quantum Turbulence in a fluid of light

Riccardo Panico[1], Paolo Comaron[2], Michal Matuszewski[3], Alessandra Lanotte[1], Daniele Sanvitto[1], **Dario Ballarini[1]**

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Turbulent flow is a striking manifestation of nonlinear dynamics observed in both classical and quantum fluids. However, while classical turbulence is ubiquitous in nature, observing quantum turbulence requires the precise manipulation of quantum fluids, such as superfluid helium or atomic Bose-Einstein condensates (BEC). In two-dimension (2D), the experimental investigation of quantum turbulence is even more challenging and optical systems, such as quantum fluids of light, offer intriguing alternatives. In particular, exciton-polaritons, bosonic quasi-particles that result from the strong interaction between light and matter in semiconductor microcavities, have been proposed as a paradigmatic family of quantum fluids of light [1].

In this talk, we show our experimental results demonstrating vortex clustering and inverse energy cascade in a polariton quantum fluid [2]. We create a highly energetic initial state by injecting the polariton fluid against a potential barrier to form a dense gas of quantum vortices. For large enough initial kinetic energy, we are able to measure the formation of correlations at larger scale; we identify the formation of cluster of vortices of the same sign, as well as the development of the universal scaling of the incompressible kinetic energy spectrum with the characteristic exponent predicted for classical turbulence. Moreover, we fully exploit the possibility to measure the phase of the quantum fluid to analyse the statistics of the velocity and vorticity fields, highlighting the analogies and differences between classical and quantum 2D turbulence.

[1] I. Carusotto *et al.*, Rev. Mod. Phys. 85, 299 (2013)
[2] R. Panico *et al.*, Nature Photonics 17, 451-456 (2023)

FR3.4 Flying Balls in Superfluid Helium

Manuel Arrayás[1], Francis Bettsworth[2], **Courtney Elmy[2]**, Daniel Field[2], Richard Haley[2], Roch Schanen[2], Daisy Smart[2], José Trueba[1], Carlos Uriarte[1], Vladislav Zavjalov[2], Dmitry Zmeev[2]

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Steady flows are seldom studied in superfluid helium due to the technical difficulties involved. Instead, oscillatory flows, whereby resonators move through the fluid, are typically studied; however, these systems are far from ideal and present many difficulties for accurate analysis. We present the first results of a tunable, superconducting levitation system [1, 2] designed to investigate both steady and oscillatory flows in superfluid helium. Indium superconducting spheres were levitated and controlled via magnetic coils in superfluid helium to produce a variety of movement profiles, including uniform linear motion, free oscillations and circular motion. From these experiments, some intrinsic properties of the superfluid have been successfully evaluated, such as the viscosity and critical velocity for turbulent flow, demonstrating the system's viability for probing superfluids. Current work includes the implementation of an electromagnetic detection system to detect the levitating sphere when optical detection is not feasible i.e. within a dilution refrigerator. This addition will eventually lead to similar experiments within superfluid helium-3. Ongoing modifications will also allow experiments to be repeated in low pressures of helium gas, providing a direct comparison between quantum and classical turbulence. The versatility of this system will enable research into many areas of interest, such as the lifetime of turbulent states above a critical velocity as described by Schoepe [3], as well as the lift experienced by an aerofoil in superfluid. It is also believed that a superfluid state free of remanent vortices could be achieved by slowly lowering the levitating ball into the superfluid from the vapour phase through the free surface.

[1] M. Arrayás et al., Sci Rep 11, 20069 (2021).
[2] M. Arrayás et al., J Low Temp Phys (2023).
[3] W. Schoepe, J Low Temp Phys 210, 539 (2023).

FR4.2 Visualizing the zero-energy surface Andreev bound states of spin-triplet superconductor UTe_2

Shuqiu Wang[1,2], Qiangqiang Gu[2], Joseph Carroll[3], Kuanysh Zhussupbekov[2,3], Sheng Ran[4], Nicholas Butch[5], Johnpierre Paglione[5,6], Xiaolong Liu[2,7], J.C. Séamus Davis[1,2,3], Dung-Hai Lee[8]

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Spin-triplet topological superconductors should exhibit many unprecedented electronic properties, including fractionalized electronic states relevant to quantum information processing. UTe_2 is a nominative topological spin-triplet superconductor, but its exact superconductive order-parameter Δ_k is still unknown. If it is a spin-triplet, it should exhibit odd parity, which means $\Delta_{-k}=-\Delta_k$, and it could potentially break time-reversal symmetry, resulting in a chiral state. A clear sign of any odd-parity superconductors is the consistent presence of a zero-energy surface Andreev bound state (SABS). Furthermore, theory suggests that certain SABS features, which can be detected through tunnelling to a s-wave superconductor, can differentiate between chiral and non-chiral Δ_k. To explore these potential phenomena in UTe_2, we use s-wave superconductive tip STM imaging and found a strong zero-energy SABS at the (0-11) crystal termination. The atomic-level visualization of this SABS shows interference patterns caused by two energy-gap nodes, which align with the crystal a-axis. Given the D_{2h} symmetry of the crystal, it is clear that the superconductive Δ_k can definitively be identified as being the odd-parity and spin-triplet state.

FR4.3 Unconventional superconductivity underpinned by antiferromagnetism in $YbRh_2Si_2$

Lev Levitin[1], Jan Knapp[1], Marijn Lucas[1], Petra Knappova[1], Jan Nyeki[1], Brian Cowan[1], Andrew Casey[1], Kristin Kliemt[2], Cornelius Krellner[2], Manuel Brando[3], Christoph Geibel[3], John Saunders[1]

[1]Physics Department, Royal Holloway, University of London, Egham, Surrey, UK
[2]Physikalisches Institut, Goethe University, Frankfurt am Main, Germany
[3]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

We present the study of interplay between magnetism and superconductivity in a heavy-fermion metal $YbRh_2Si_2$, probed with high-resolution measurements of electrical impedance and heat capacity down to 0.2 mK, using novel ultra-sensitive SQUID-based experimental techniques.

In addition to the well-established antiferromagnetism (AFM) below the Néel temperature T_N = 70 mK we observe a second AFM order with onset T_A = 1.5 mK, stabilised by hyperfine interactions in ^{171}Yb and ^{173}Yb. From signatures in calorimetry and magnetoresistance we map the suppression of T_N and T_A with magnetic field, applied in the ab plane of the tetragonal single crystals of $YbRh_2Si_2$.

The superconductivity manifests below 10 mK as zero resistance or a partial resistance drop. Simultaneously the imaginary part of the sample impedance develops, that we attribute to the kinetic inductance. The sample-to-sample variation and the absence of transition signatures in the heat capacity between 2 and 10 mK point towards inhomogeneous superconductivity. Different transport signatures of superconductivity exhibit distinct dependence on the magnetic field, both Pauli-limited and beyond the Pauli limit, suggestive of spin-triplet pairing and multiple superconducting order parameters, possibly with non-trivial topology.

Importantly the superconductivity is switched off at the critical field of the primary AFM order; moreover the impedance abruptly changes across the phase boundary between the two magnetic phases. We conclude that the superconducting order parameters formed in $YbRh_2Si_2$, are sensitive to the magnetic state of the sample and require the presence of AFM order. An intriguing scenario is spin-triplet pairing mediated by ferromagnetic fluctuations.

FR4.4 Light Induced Magnetism via Inverse Faraday Effect

Priya Sharma[1], Alexander Balatsky[1,2]

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[2]Theoretical Quantum Matter group, NORDITA, Stockholm, Sweden

We present a microscopic calculation of the inverse Faraday effect in metals. We derive a static local magnetic moment induced on the application of high-frequency light, using the Eilenberger formulation of quasiclassical theory. We include the effect of disorder and formulate a theory applicable across the entire temperature range, in the absence of external applied fields. For light-induced electric fields of amplitude ~ 100 kV/cm, the induced fields are large, ~ 0.1 T for metallic Nb! The predictions of our theory agree with recent experimental and theoretical results [1,2]. An extension of this approach to superconductors would open a new route of inducing orbital magnetic field and potentially vortices in superconductors.

1. O. H.-C. Cheng, D. H. Son, and M. Sheldon, Light-induced magnetism in plasmonic gold nanoparticles, Nature Photonics 14, 265 (2020).
2. J. Hurst, P. M. Oppeneer, G. Manfredi, and P.-A. Hervieux, Magnetic moment generation in small gold nanoparticles via the plasmonic inverse Faraday effect, Phys. Rev. B 98, 134439 (2018).

4.4 Poster Presentations: Friday 11th August

FR5.1 **Measurements of Helium Mixtures by Neutron Absorption**

Christopher Lawson, **Alex Jones**, Winfried Kockelmann, Sasha Horney, Oleg Kirichek

ISIS Neutron and Muon Source, Science and Technology Facilities Council, Didcot, United Kingdom

We present a new, non-invasive and real-time technique for investigating the properties of helium-3/4 mixtures via neutron absorption. The large differential microscopic neutron absorption cross section between ^{4}He (σ_4 = 0.0075 b) and ^{3}He (σ_4 = 5333 b) for 1.8 Å neutrons allows extremely high contrast observations of different phases, and measurements of the relative concentrations of each isotope. We demonstrate this with a proof-of-concept measurement made in conjunction with our imaging of an operational dilution refrigerator [1] on the IMAT neutron imaging instrument [2] at ISIS Neutron & Muon Source.

In this proof-of-concept, we were able to observe the boundary between the concentrated ^{3}He and dilute ^{3}He phases in the mixing chamber of the dilution refrigerator and could examine the change in dilute phase concentration with temperature. Here, we demonstrate the method for making measurements of ^{3}He concentration at arbitrary locations within a spatially complex system and suggest the expansion of this technique for observing phase boundaries in other helium systems, e.g., solid ^{3}He.

[1] C.R. Lawson *et al.*, Sci. Rep. **12**, 1130 (2022).
[2] T. Minniti *et al.*, Nucl. Instrum. Methods Phys. Res. A **888**, 184–195 (2018).

FR5.2 **Performance Evaluation of the Nanopore Heat Exchanger**

Azimjon Temurjonov[1], Taku Matsushita[1], Mitsunori Hieda[2], Nobuo Wada[1]

[1]Department of Physics, Nagoya University, Nagoya, Japan, [2]College of Liberal Arts and Sciences, Tokyo Medical and Dental University, Ichikawa, Japan

Heat exchangers for liquid helium usually involve sintered 70 nm Ag powder which reduces Kapitsa 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 (~5 µm at 10 mK) is bigger than the distance between grains (~70 nm), thermal resistance of the He mixture becomes significant due to the scattering of quasiparticles with grains. Here we report on nanopore heat exchanger [1] where Ag powder with grains of 70 µm (distance ~70 µm) filled with the nanopores is used. In our system Kapitsa resistance can be controlled by using nanopores as it has a huge specific area ~1000 m^2/g. As an experimental result (T > 23 mK), the nanopore exchanger 10 times smaller than the traditional 70 nm-Ag sponge exchanger showed the same heat flow resistance. Further increase of nanopores and silver can even lower the heat flow resistance. It can be examined, for example, based on the ladder model [2]. However, previous study neglected silver thermal resistance, while in our exchanger thermal resistance of the mixture is expected to be comparable with that of the sinter. Therefore, a more detailed model is needed for a realistic device and currently it is under preparation.

[1] Patent number: JP-7128544, Patent application number: US16/975,511, CN201980015009.0.
[2] D. J. Cousins *et al.*, Phys. Rev. Lett. **73**, 2583 (1994).

FR5.3 Development and testing of a low-frequency, high-amplitude, torsional oscillator for cryogenic studies.

Anthony M Guénault[1], Peter V. E. McClintock[1], Malcolm Poole[1], **Roch Schanen[1]**, Viktor Tsepelin[1], Dmitry E. Zmeev[1], David Schmoranzer[2], William F. ("Joe") Vinen[3], Deepak Garg[4], Kalpana Devi[4]

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[2]Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic
[3]School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
[4]D.A.V. College, Panjab University, Chandigarh, India

We present a low-frequency torsional oscillator suitable for studies of quantum fluids and solids. It operates at frequencies of the order of 100 Hz and can achieve velocities of several centimetres per second, with a quality factor of 30,000. In order to reach such velocities at this relatively low frequency, the oscillator amplitude must exceed hundreds of micrometres, which is impracticable for a conventional capacitor-driven device where the drive is applied parallel to the main motion. A different geometry of oscillator is here described, where the relevant forces and movements are all tangential to the capacitor surface, so that the separations of both the drive and detect capacitor plates remain constant, independent of the amplitude of oscillation [1]. This novel design will be discussed. Its calibration and detailed tests of its performance at different temperatures will be reported. Its potential advantages, and the opportunities it opens up for future research, will be considered.

[1] Anthony M. Guénault, Peter V. E. McClintock, Malcolm Poole, Roch Schanen, Viktor Tsepelin, Dmitry E. Zmeev, David Schmoranzer, William F. (“Joe”) Vinen, Deepak Garg, Kalpana Devi, “A low-frequency, high-amplitude, torsional oscillator for studies of quantum fluids and solids”, *Physics of Fluids* **35**, 045146 (2023).

FR5.4 Carbon Footprint of the Helium Recovery System at the ISIS Neutron and Muon Source

Richard Down, Alexander Jones, Christopher Lawson, Oleg Kirichek

ISIS Neutron and Muon Source, Science & Technology Facilities Council, Didcot, United Kingdom

Helium is a global finite resource, which is becoming vitally important to recover and reuse as it continually diminishes. The Helium recovery process is well known and incorporates plant machinery that can consume significant amounts of power, thus contributing to a facility’s already large carbon footprint.

The drive to reduce carbon footprint, and therefore lessen the impact of climate change, is gathering momentum. In this work we have assessed the CO_2 produced per liquid litre of Helium, when processed by the ISIS Helium Recovery Facility. The main components have been taken into consideration, including high-pressure compressors, instrumentation, Linde KryoTecnique TCF20 cold box, screw compressor, building infrastructure and safety systems.

Furthermore, once the carbon footprint had been obtained, a comparison was carried out to see how in-house Helium production compares with liquid Helium that is supplied by the gas companies. To do this we have explored the liquefaction process of both liquid natural gas and Helium, the methods of transportation that are employed, the time taken to transport and the liquid boil off rates during the delivery process.

This allows us to comment on the contribution Helium recovery can make in the pursuit of Net Zero.

FR5.5 **Design of He-3 immersion cell to study low-dimensional electron systems**

Rasul Gazizulin[1], Zhengguang Lu[2], Tonghang Han[2], Chao Huan[1], Lucia Steinke[1], Mark W. Meisel[1], Long Ju[2]

[1]MagLab High B/T Facility and Department of Physics, University of Florida, Gainesville, FL, USA,
[2]Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, USA

Achieving proper thermalization and filtering of samples, along with electromagnetic filtering of connecting wiring, to ultra-low temperatures is essential for the discovery of new quantum phenomena. This task becomes particularly challenging for low-dimensional electron systems in nanodevices due to electron-phonon decoupling with strong temperature dependence and heat leaks from electromagnetic noise [1]. To address these challenges, cooling methods involving immersion in liquid He-3 [2,3] and nuclear demagnetization of each lead [4] have been introduced. In this work, recent progress in designing an immersion cell and its implementation on a cryogen-free dilution refrigerator, available for user experiments at the MagLab High B/T Facility, will be presented. The preliminary data on cooling a low-dimensional electron system in a pentalayer graphene device [5] will be shown.

Work performed at the MagLab is supported by NSF DMR-2128556 and the State of Florida.

[1] M. Sarsby et al., *Nature Communications* 11, 1492 (2020).
[2] W. Pan et al., *Physical Review Letters,* 83, 17, 3530 (1999).
[3] L.V. Levitin et al., *Nature Communications* 13, 667 (2022).
[4] A. Clark et al., *Review of Scientific Instruments,* 81, 103904 (2010).
[5] T. Han et al., *arXiv:2305.03151* (2023).

FR5.6 **Study of thermal boundary resistance between ^{3}He and solids at ultralow temperatures**

Petra Knappová[1], Lev Levitin[1], Harriet van der Vliet[2], Jan Nyéki[1], **Andrew Casey**[1], John Saunders[1]

[1]Department of Physics, Royal Holloway, University of London, Egham, UK
[2]Quantum Technologies, Oxford Instruments, Abingdon, UK

Creating the best thermal contact between liquid helium and solids is critical when cooling samples to ultralow temperatures. 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 [1].

In this report we present results obtained from a compact, versatile experimental cell that enables the test of small area samples of materials that are candidates for novel future heat exchangers, of importance in improved dilution refrigerators and the cooling of quantum materials and quantum sensors. The technique uses a low dissipation, integrated SQUID-based current sensing noise thermometer to measure the temperature of the sample (square cm sized foils) in response to the application of heater power (in pW range). The heat leak to the samples is minimised by suspending them via superconducting leads .

The setup allows for the systematic study of heat transport across a well-defined boundary to liquid ^{3}He for a wide range of materials. In this configuration we can investigate the influence of magnetic impurities in the test materials, the role of the helium surface boundary, and the field dependence. In addition, the low heat leak into the test material allows the sample to cool below the superfluid transition temperature of the helium, such that changes in thermal resistance arising from the onset of superfluidity in ^{3}He can be investigated.

[1] S. Autti et al., Phys. Rev. B 102, 064508 (2020)

FR5.7 Vibrating carbon nanotubes: A nanomechanical probe to study quantum phenomena in superfluid

Saba Khan, Edward Laird

Physics Department, Lancaster University, Lancaster, United Kingdom, UK

This project explores dissipation in superfluid helium by studying the vibrations of carbon nanotubes. Carbon nanotubes are excellent nanomechanical resonators with high crystallinity, low contamination, and atomic-scale mass sensitivity. Superfluidity in ^{3}He or ^{4}He is a fascinating phenomenon that arises from quantum mechanics at the microscopic level.

To obtain pristine nanotube resonators, we have developed a fabrication process involving the growth of nanotubes in the final step. With our chip design and the modified chemical vapor deposition (CVD) recipe, we are able to grow nanotubes across a trench up to 70% of the time. To measure the vibrations of these resonators inside the superfluid ^{4}He, we have integrated two helium gas fill lines into a commercially available dry fridge, with custom-made heat exchangers at each thermal stage to lower the helium gas temperature below the transition temperature. Additionally, we have designed a helium-cell equipped with 24 DC and 6 RF feedthroughs, incorporating a silver sinter to maintain the superfluid temperature within the cell. Within this cell, a specially designed printed circuit board (PCB) allows for the simultaneous characterization of multiple nanotube resonators using both DC and AC measurement schemes.

Characterising the nanotube resonators in vacuum confirms their high quality, with transport measurements allowing for the calculation of energies associated with excited states. Preliminary measurements of nanotubes inside the superfluid show a slight downward frequency shift and increased damping, requiring further investigation to determine if it is due to temperature variation or interaction with superfluid helium itself.

FR5.8 Probing Superfluid 4He with Oscillating Carbon Nanotubes

Scott Henderson, Edward Laird

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Single-walled carbon nanotubes are extremely sensitive electromechanical probes used extensively in quantum and low-temperature research. While the influence of monolayer helium on these devices has been investigated in [1], little is known about their behavior in bulk helium-4 or helium-3. This research sets out a theoretical method for controlling and measuring these mechanical oscillators in bulk helium-4, accompanied by predictions of their behavior.

[1] Todoshchenko, I., Kamada, M., Kaikkonen, JP. et al. Topologically-imposed vacancies and mobile solid ^{3}He on carbon nanotube. Nat Commun 13, 5873 (2022).

FR5.9 Fully suspended mechanical probes for quantum fluids.

Ilya Golokolenov[1], Sumit Kumar[2], Baptiste Alperin[1], Bruno Fernandez[1], Andrew Fefferman[1], Eddy Collin[1]

[1]MCBT, Institut Néel, Grenoble, France
[2]Physics, Royal Holloway University of London, Egham, Surrey, United Kingdom

Non-invasive probes are keystones of fundamental research. Their size, and maneuverability (in terms of e.g. speed, dissipated power) define their applicability range for a specific use. As such, solid state physics possesses e.g. Atomic Force Microscopy (AFM), Scanning Tunneling Microscopy (STM), or Scanning SQUID Microscopy. In comparison, quantum fluids (superfluid ^{3}He, ^{4}He) are still lacking probes able to sense them (in a fully controllable manner) down to their smallest relevant lengthscales, namely the coherence length. In this work we report on the fabrication and cryogenic characterization of fully suspended (hanging over an open window, with no substrate underneath) SiN nano-beams, of width down to 50 nm and quality factor up to 10^6.

The analytical model of "natural soft clamping", which can help design high Q devices in the future, is provided and verified on experimental data. As a benchmark experiment we used them to investigate the Knudsen boundary layer of a rarefied gas: ^{4}He at very low pressures. The absence of the rarefaction effect due to the nearby chip surface is attested, while we report on the effect of the probe size itself.

FR5.10 Two-dimensional plasmons in microchannel confined electrons on helium

Camille Mikolas[1], Niyaz Beysengulov[2], Johannes Pollanen[1]

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[2]EeroQ, Chicago, United States

Electrons floating above the surface of superfluid helium (eHe) are a unique platform to investigate the high-frequency collective dynamics of ultra-high mobility trapped electron systems. Here we present the results of recent experiments in which the electron system is simultaneously subjected to microchannel confinement and GHz-frequency microwave excitation. The microchannel device provides precision control of the electron density and enables access to both quasi-one-dimensional electron chains as well as two-dimensional electron sheets. In this device, we observe density-dependent resonant features in the electron transport data, which originate from collective excitations of the electron system in the microchannel. We identify these collective excitations with two-dimensional plasmon modes of the electron system confined in the microchannel. Additionally, we present progress on developing hybrid devices composed of microchannel eHe systems coupled to superconducting coplanar waveguide resonators, which can aid in the development of future quantum information science technologies based on trapped electrons.

FR5.11 Correlated transport of electrons on helium through a gate-defined island

Austin Schleusner[1], Niyaz Beysengulov[1], Camille Mikolas[1], David Rees[2], Johannes Pollanen[1]

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Field-effect control of low-dimensional electron systems in nanoscale devices has enabled the exploration of a wide variety of mesoscopic quantum phenomena in semiconductors such as the quantized electrical conductance produced by Coulomb blockade effects. In contrast to semiconductor systems, electrons trapped at the boundary of a liquid helium-vacuum interface realize a non-degenerate two-dimensional electron system with ultra-high mobility and unique mesoscopic transport behavior when subjected to microchannel confinement. Here we report on the transport behavior of strongly-interacting liquid and solid states of electrons on helium through a controllable electron-island gate. Our results reveal the effect of Coulomb interaction-induced correlations in each phase as the electrons are transported through the island/constriction. Additionally, we investigate the breakdown of the resonant Bragg-Cherenkov effect as we controllable introduce disorder to the electron systems via the gate-defined island.

FR5.12 Fast charge sensing for quantum-state detection in electrons on helium

Jui-Yin Lin, Tomoyuki Tani, Denis Konstantinov

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

The readout of qubits requires high operating speed and charge sensitivity. Based on radio frequency reflectometry [1], we report here the development of an extremely sensitive, fast, and noninvasive electrometer for quantum-states detection of electrons on helium .

Our approach involves the use of a superconducting tank resonator connected to a Corbino device. The electron transition between Rydberg states results in a small change in the effective capacitance incorporated into the tank circuit. The dynamics of this capacitance change cause external harmonic signals to emerge, which we detect using a 50-MHz resonant circuit embedded in the device. Via tuning to perfect impedance matching between the tank circuit and a 50-Ω transmission line, an optimized capacitance sensitivity of 0.058 $aF/Hz^{1/2}$ is achieved at 30-Hz bandwidth. An advantage of our method is that it allows for potentially high measurement bandwidths (up to 1 MHz), which is crucial for fast qubit-state readout.

Overall, our development represents a significant advance toward quantum computing, as it provides a highly sensitive and non-invasive method for detecting the quantum states of electrons on helium. This could have important applications in the development of future quantum technologies.

[1] R. J. Schoelkopf, P. Wahlgren, A. A. Kozhevnikov, P. Delsing, and D. E. Prober, The Radio-Frequency Single-Electron Transistor (RF-SET): A Fast and Ultrasensitive Electrometer, Science 280, 1238 (1998).

FR5.13 **Rydberg Transition of Surface State Electrons on Liquid ^{4}He Sensed by RF-Reflectometry**

Tomoyuki Tani, Jui-Yin Lin, Denis Konstantinov

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

Surface State Electron (SSE) on liquid helium is an ideal ground to study the quantum properties of 2-dimensional electron system in an environment free from impurities and defects [1,2]. Recently, SSEs on liquid helium has been attracting much interest in the context of quantum computing, following several theoretical proposals which suggest their use as qubits [3-5].

To achieve a fast read-out of the qubit states, we have developed the method to detect the Rydberg transition of SSEs with high sensitivity based on RF-reflectometry. With this method, we successfully observed the Rydberg transition in a many-electron system on bulk liquid ^{4}He with small microwave power for the Rydberg excitation down to several hundred pW. The high sensitivity will enable us to detect the dynamics of small number of SSEs as few as 10^3. Furthermore, by the application of micro-sized structures which confine electrons close to the detection electrodes, we expect to achieve the ability to read-out the quantum state of single electron. In the presentation, details of our experimental results including some unexpected resonant signals will be discussed.

[1] Y. Monarkha and K. Kono, *Two-Dimensional Coulomb Liquids and Solids*, (Springer-Verlag, Berlin, 2004)
[2] D. Konstantinov and K. Kono, Phys. Rev. Lett. **105**, 226801 (2010)
[3] P. M. Platzman and M. I. Dykman, Science **284**, 1967 (1999)
[4] D. I. Schuster, *et. al.*,Phys. Rev. Lett. **105**, 040503 (2010)
[5] E. Kawakami, *et. al.*, arXiv:2303.03688v1 (2023)

FR5.14 **Resonant image charge detection for e^-@He qubit**

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Fundamental limitations of superconducting qubits forced the search for new alternative quantum systems for qubit realization. Coherence time of spin state on the order of seconds and mobile qubit architecture favor electrons on the superfluid film of helium among other candidates for realization of scalable quantum computer [1]. At the current early stage of development, the realization of e^-@He qubit requires a reliable readout of Rydberg states, which will pave the way to spin state readout via artificial spin-orbit coupling.

In this presented work we aim at image charge detection of electron’s Rydberg transitions using a microchannel device with superfluid helium film to trap and control electrons. A high-quality LC tank circuit is used for electron’s image charge detection. We can resonantly accumulate electron’s image charge current by driving electron’s Rydberg transition with a pulse-modulated microwave radiation set to the resonant frequency of the tank circuit. Finally, the voltage across the LC tank is detected using a cryogenic low noise amplifier [2].

Presently, with CryoHEMT based cryogenic amplifier and superconducting tank circuit we managed to achieve 7.46 nV/Hz$^{1/2}$ noise level in detection system with quality factor 985 and resonance frequency 835 kHz. With an expected single electron image charge current of 3.9 fA in a microchannel device, we estimate 0.2 s measurement time for the spin state of a single electron.

[1] S. A. Lyon, Phys. Rev. A 74, 052338 (2006).
[2] E. Kawakami, Phys. Rev. Lett. 126, 106802 (2021).

FR5.15 Integration of a cryogenic LC circuit for image-charge detection for surface electrons on helium

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[2]B. Verkin Institute for Low Temperature Physics and Engineering, National Academy of Sciences of Ukraine, Kharkiv, Ukraine
[3]Cluster for Pioneering Research, RIKEN, Wako, Japan

Surface electrons (SEs) on liquid helium present a promising candidate for scalable quantum computing, with the spin-state coherence time on the order of seconds [1]. We propose to use a hybrid qubit by coupling the spin state of the SE to the hydrogen-like Rydberg state [2]. In order to detect the qubit state, we must be able to detect the excitation of the Rydberg state of a single SE. To this end, the image-charge detection technique was developed and has been successfully applied to many SEs [3].

Pursuing the goal of improving the sensitivity of this method for a single SE, we integrated a high-Q factor LC-tank circuit with the image-charge detection technique. Here, we present the detection of the Rydberg state of many SEs using the LC circuit. The capacitor comprises a variable capacitance for tuning the resonance, and two detection electrodes between which the SE are held. The capacitance of the circuit then depends on the position of SEs between the electrodes, and thus the Rydberg state. We estimate that the transition between the Rydberg states of a single SE would lead to an AC capacitance change of 40 aF [2]. The optimized capacitance sensitivity [4] was measured to be S_C = 7 aF/√Hz with f_0 = 90 MHz at 1 K. We further discuss improvement of the LC circuit using a microfabricated superconducting inductor.

[1] P.M. Platzman, and M.I. Dykman, Science 284, 1967 (1999).
[2] Kawakami et al., arxiv:2303.03688 (2023).
[2] E. Kawakami, A. Elarabi, and D. Konstantinov, Phys. Rev. Lett. 123, 086801 (2019).
[3] N. Ares et al., Phys. Rev. Applied 5, 034011 (2016).

FR5.16 Electron transport on thin helium films across mm-long transport line

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Electron transport over thin helium films opens the door to probing new 2D electron phase transitions because of the higher electron densities that van der Waals enhanced films can support. However, transport is often difficult because of potential barriers that arise from rough metal surfaces or gaps in gates due to the abrupt absence of electron image charge attraction. Here, we present a device design which mitigates these issues and demonstrates the transport of electrons across a thin continuous 5.6 um wide, 4 mm long wire coated with a vdW thin helium film. The wire is fabricated from amorphous, resistive (0.8 MΩ at 1.7K) NbSi which allows for transport due to the ultrasmooth surface and lack of grain boundaries. With the use of tapered fingers that gradually lower the helium thickness, we smoothly move electrons between thin film and thick regions of helium at either end consisting of 700 nm tall, 10 um wide channels patterned above three electrodes to measure electron densities using the Sommer-Tanner method. To measure electron mobilities, we conduct time of flight measurements by pulsing “door” gates located at both ends of the transport line positive and negative, controlling the movement of electrons in and out of the thin film region. In sweeping the gate pulse durations, we report on a lower bound mobility of 2700 cm^2/Vs over a 34 nm film. Furthermore, the integration of interdigitated capacitors sandwiching the thin film transport channel allows for electron mobility measurements over a variety of helium depths.

FR5.17 Proposal Towards Transient Enhancement of Electron Density Above Liquid Helium into the Quantum Degenerate Regime

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Electrons above liquid helium provide a unique platform to study the interactions of electrons in the two-dimensional (2D) limit. As the number of electrons is increased, the surface of the liquid eventually becomes unstable due to an electrohydrodynamic instability (EHD). This restricts the areal density of surface electrons to a maximum of approximately 2.4×10^{13} m^{-2} above the bulk liquid and somewhat higher above helium films. We propose an experimental configuration where it may be possible to achieve an electron density orders of magnitude higher than before the EHD sets in. The proposal centers on rapidly adjusting the electrode potentials to achieve high electron densities and making a transient measurement of the 2D electron system.

FR5.18 Focusing Ultrasound in Superfluid Helium-4 using a Fresnel Zone Plate

Dillip Kumar Pradhan[1], Ayanesh Maity[2], Ambarish Ghosh[1,2]

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Focussed ultrasound in liquid and superfluid helium is used to study and visualize single and few-electron bubbles, generate quantized vortices, and probe the interaction between ions and vortices. Conventional approaches rely on hemispherical ultrasonic transducers, while cylindrical shapes have recently been reported. While the focussing is necessary to generate intense ultrasound, there are inherent limitations associated with the focussing being done at a single point or along a line. In addition, the curved geometry makes it difficult to create a spatially uniform electric field, which is often necessary to perform ion mobility measurements. Recently, we have proposed and developed a novel approach for focusing ultrasound on liquid helium using a Fresnel zone plate. This focusing technique offers significant advantages over the traditionally used curved transducer geometry, primarily due to its planarity and the existence of multiple foci. We will present preliminary experimental data and compare it with the numerical calculations.

FR5.19 **Effect of Convective Flow on the Dynamics of Multielectron Bubbles in Liquid Helium-I**

Neda Shamim, Dillip Kumar Pradhan, Vaisakh Vadakkumbatt, Ambarish Ghosh

Centre for Nano Science and Engineering, Indian Institute of Science, Bengaluru, India

Multielectron Bubbles (MEBs) are cavities inside liquid helium containing electrons and helium vapor. MEBs provide a versatile platform to explore the uncharted regions of 2DES phase diagram, for which it is necessary to make an accurate and non-destructive estimate of the number of electrons inside the bubbles. Typically, the charge is estimated by analyzing the trajectory of an MEB under a known electric field and comparing the experimental results with numerical simulations for various values of charge. However, under certain experimental conditions, there can be convective flow in the system which interferes with this methodology. To understand the role of convection, we engineered the convective flow within the experimental chamber by applying heat above and below the chamber in different ratios and observed the MEBs rise under buoyancy. The experimentally measured terminal velocities of the MEBs were found to match with theoretical estimates when the convective flow was negligible. These experiments were performed at 2.5 K. To establish this was indeed the condition for zero convective flow, we measured the rate at which the vapor inside the bubbles condensed. The results were close to the theoretical estimate based on vapor condensation due to thermal conduction in the bulk liquid.

FR5.20 **Using a cylindrical piezoelectric transducer to focus ultrasound in superfluid helium**

Dillip Kumar Pradhan, **Shriganesh Neeramoole**, Neha Yadav and Ambarish Ghosh

Centre for nanoscience and Engineering, Indian Institute of Science, Bangalore, India

Ultrasound in bulk liquid and superfluid helium has been used for multiple studies, including generation of quantum turbulence, and inducing homogenous or heterogenous cavitation. Both hemispherical and planar ultrasonic transducers have been used in the past, which optimize the focusing volume and the degree of focusing. In this paper, we demonstrate the application of a cylindrical piezoelectric transducer to achieve a linear focusing configuration. We have developed a new method to calibrate the pressure generated by the ultrasonic transducer, where we measured the threshold ultrasound drive at which mist was observed. The results were compared with those from a hemispherical geometry. The linear focusing configuration was further demonstrated to observe the cavitation of single electron bubbles arranged in a linear array. Our experiments are relevant to studies in liquid helium that require large pressure oscillations in controlled volumes.

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FR5.21 Trapping Sound with Light

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Cavity optomechanics is a powerful tool for developing sensing applications and controlling mechanical systems that relies on coupling an optical cavity to a mechanical resonator. This coupling is generally limited to optical interactions that perturbs a pre-existing mechanical eigenmode. Although the idea of optically generating mechanical eigenmodes has been proposed, solid materials are too stiff to make this possible. Using recent advancements made by our group to drive superfluid mechanical modes with thermal effects, we're leveraging the extreme compliance of superfluid helium to achieve this. We propose this through the use of silicon photonic chips, which have been planarized to remove geometric boundary conditions using a HSQ cladding. Due to the fountain pressure which draws fluid towards a heat source, we will use the buried optical resonator to create a heat map that will define a thermal potential for attracting superfluid in a thin film. This will define an acoustic boundary condition in the superfluid film, allowing an intrinsic acoustic resonator to appear in the superfluid due to the presence of the optical field buried in the cladding. Building on our experience with superfluid optomechanics, we can use this to make fluidic circuits that allow the controlled interaction of phonons in this novel superfluid acoustic landscape for sensing applications and for fundamental investigations of the properties of superfluid helium including quantized vortices and turbulence. I will be discussing progress towards this work including development of a cryogenic packaging system that allows easier testing of superfluid optomechanical devices.

FR5.22 Coherent structures and turbulence in fuzzy dark matter haloes

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We show that fuzzy dark matter haloes exhibit spatial differentiation in the coherence of the field configuration, ranging from completely coherent in the central solitonic core to incoherent outside it, with a significant drop of the dimensionless phase-space density with increasing radius. The core can be regarded as a pure condensate, overlapping perfectly with the Penrose-Onsager mode corresponding to the largest eigenvalue of the one-particle density matrix. The virialized outer halo exhibits no clear coherence as a whole upon radial and temporal averaging but can be described as a collection of local, short-lived quasi-condensate lumps, exhibiting suppressed fluctuations, which can be identified with the structures commonly referred to as granules. These localized regions are separated by vortices that form a dynamical web, inhibiting phase coherence across the entire halo. We further examine the core oscillations, finding that they are accurately described by two time-dependent parameters characterizing the size of the coherent core and a crossover region size. For the haloes in our merger simulations, this feature is reflected in the (anti-)correlated oscillation of the peak value of the density power spectrum. The halo's turbulent vortex tangle appears to reach a quasi-equilibrium state over probed time scales Comparison of the peak wavenumbers in the corresponding power spectra show the inter-vortex spacing and the granule length scale in the outer halo to be very similar and slightly above the core size.

FR5.23 Anisotropic Collective Mode of Self-Gravitating Bose-Einstein Condensates

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We theoretically study the self-gravitating Bose-Einstein condensates (BECs). Recently some astrophysicists and cosmologists are interested in the self-gravitating BEC as a possible candidate of dark matter. They expect that dark matter plays a crucial role as a source of gravity in astrophysical phenomena and the self-gravitating BEC describes the behavior of dark matter.

The self-gravitating BECs are quite different from ordinary atomic BECs in terms of following two great properties. One is that the configuration is formed by the competition between the self-gravity and the repulsive contact interaction. Then the self-gravitating BEC does not require any external potentials for the formation of its bounded configuration while ordinary atomic BECs need to be trapped by external potentials to form the configurations. The other is the complicated quantum-hydrodynamic description due to the density dependence of the self-gravity. In the case of the self-gravitating BEC, its density profile generates its own gravitational potential, and the gravitational potential affects the density profile of the BEC. This property is unique because the trapping potentials of ordinary atomic BECs are independent of the profiles of BECs.

We numerically solve the three-dimensional Gross-Pitaevskii-Poisson equations which describe the self-gravitating BECs. At the international conferences LT29 and ULT2022 we reported our results on the breathing mode of the self-gravitating BEC. In this work, we simulate an anisotropic collective mode that exhibits the breathing mode coupled with the quadrupole mode. Furthermore, we analyze the anisotropic collective mode by the variational method. It shows good agreement with our numerical simulations.

FR5.24 Superfluid Helium-3 Bolometers for a Direct Dark Matter Search

Tineke Salmon[1], Samuli Autti[1], Neda Darvishi[2], Paolo Franchini[1,2], Richard Haley[1], Ashlea Kemp[2], Elizabeth Leason[2], Lev Levitin[2], Jocelyn Monroe[2], Robert Smith[2], Stephen West[2], Vladislav Zavyalov[1], Dmitry Zmeev[1]

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The QUEST-DMC (QUantum Enhanced Superfluid Technologies for Dark Matter and Cosmology) collaboration is conducting a direct dark matter search using superfluid helium-3 as a target. Dark matter is inferred from gravitational lensing, galaxy rotation curves, cosmic microwave background, and a bullet cluster, as it does not interact with electromagnetic fields. The goal of the experiment is to detect spin-dependent interactions in the sub-GeV mass range as heat deposited in the superfluid in the eV range. To achieve this, the He-3 is cooled down to 100 µK, where broken Cooper pairs generate thermal excitations with energy 10^{-7} eV. By moving a probe rod in the superfluid and measuring changes in the drag force, energy deposited by a dark matter collision can be detected. Simulations of background events and nuclear and electron recoil energies have been conducted. To ensure the radiopurity of the experiment and to facilitate the correct interpretation of the background signal, radioassays have been completed. The He-3 target is contained in a bolometer box, which has been calibrated using the width parameter response of a wire resonator after injecting heat. Ongoing work includes calibrating the bolometers for energy deposits and incorporating photon detection as a secondary signal. Additionally, a SQUID (Superconducting QUantum Interference Device) is being tested as a less noisy alternative to the direct readout of the wires used presently. Here we discuss the preliminary results of the collaboration such as the bolometer calibration. This abstract was written on behalf of the QUEST-DMC Collaboration.

FR5.25 **Proposal for analogue gravity using thin superfluid ^{4}He films**

Zara Graham Jones, Sumit Kumar, Matthew Kenworthy, Xavier Rojas

Department of Physics, Royal Holloway University of London, Egham, United Kingdom

In this work, we present a proposal for an analogue gravity experiment to simulate black holes. Our system consists of gravity waves at the surface of thin circular super-fluid ^{4}He films. An effective gravitational force is generated from the strong Van-der-Waals interaction between the substrate and the surface of the film. This leads to a gigantic gravitational pull when using films of nanometric thicknesses, which we can exploit to enable relatively large wave velocities, and a linear dispersion on a broad frequency range. This work presents finite-element modelling simulations to analyse the acoustic physics of these surface waves in the presence of a background flow. To simulate a black hole, we introduce a vortex on the surface of the thin super-fluid ^{4}He film, such that the acoustic event horizon is representative of a black hole event horizon. Our models predict that compared to a stationary background flow, the frequencies and shape of the eigenmodes shift measurably when we introduce a background vortex flow. The model also predicts that there are temperature, density and acoustic pressure variations that are unique to the region inside the future apparent horizon of the vortex.

4.5 Invited Oral Presentations: Saturday 12th August

SA1.1 **Rotating dipolar quantum gases: Vortices, supersolids, and glitches**

Thomas Bland[1], Elena Poli[1], Lauritz Klaus[1,2], Claudia Politi[1,2], Eva Casotti[2], Giacomo Lamporesi[3], Russell Bisset[1], Manfred Mark[1,2], Francesca Ferlaino[1,2]

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Since the first observation of a Bose-Einstein condensate (BEC) made of strongly dipolar quantum gases, these systems have proven to be a rich source of new and fascinating phenomena arising from the long-range and anisotropic dipole-dipole interaction. Here, we will present the latest results from our ultracold dipolar quantum gas research in Innsbruck, with a particular focus on the rotational properties of these systems in different phases. The presence of quantized vortices – topological defects of the condensate wavefunction characterized by a 2π phase winding around the vortex line – consists of one of the most distinctive manifestations of their superfluid nature. We report on the first experimental observation of quantized vortices in a strongly magnetic BEC of dysprosium atoms by stirring the gas through rotating the magnetic field, using a novel technique exploiting magnetostriction due to the dipole-dipole interaction. We observed the vortex cores arrangement into stripes aligned along the magnetic field direction, an effect which becomes absent when turning the magnetic field parallel to the rotation axis. These results open the door for studying more complex phases of matter under rotation, such as dipolar supersolid states, that simultaneously manifest a crystalline order – typical of a solid – and superfluid properties. Indeed, recently observed two-dimensional supersolids pave the way to investigate the dynamical properties of the system during rotation, and we show that the intrinsic supersolid lattice provides a suitable platform to model vortex unpinning between lattice sites giving rise to glitches, in analogy to the inner dynamics of neutron stars.

SA1.2 **Dimensionality crossover in a weakly interacting atomic Bose gas and the dynamics of quantum droplets: A study of phase transitions**

Nick Keepfer[1], Nick Proukakis[1], I-Kang Liu[1], Franco Dalfovo[2], Tom Billam[1], Nick Parker[1], Thomas Flynn[1]

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We present a comprehensive numerical study on the equilibrium properties of a weakly interacting atomic Bose gas across the Berezinskii-Kosterlitz-Thouless (BKT) and Bose-Einstein condensation (BEC) phase transitions through a dimensionality crossover from two to three dimensions and additionally investigate the dynamics of quantum droplets through an instantaneous quench.
The dimensionality crossover is realized by confining the gas in a hybridised trap, providing homogeneity along the planar xy-directions through a box potential and a harmonic transverse potential along the z-direction. The dimensionality is modified by varying the frequency of the harmonic trap from tight to loose transverse trapping. By employing a stochastic (projected) Gross-Pitaevskii equation, our findings reveal a continuous shift in the character of the phase transition from BKT to BEC, and a monotonic increase of the identified critical temperature as a function of dimensionality, with the strongest variation exhibited for small chemical potential values up to approximately twice the transverse confining potential.
In addition, this work explores the dynamics of quantum droplets within homonuclear mixtures in the context of instantaneous quenches into the droplet regime. We investigate the effects of quenches on the behavior of quantum droplets, and how it offers insights into their properties, formation, stability and dynamics.
Combining the studies of dimensionality crossover and instantaneous quenches, this talk will provide a deeper understanding of the complex behavior of quantum droplets and the phase transitions in weakly interacting atomic Bose gases, and their implications for future experimental investigations.

SA2.1 Superfluid helium-3 under mesoscopic confinement: low magnetic fields and phase transitions

Petri Heikkinen[1], Nathan Eng[1], Lev Levitin[1], Xavier Rojas[1], Angadjit Singh[1], Anton Vorontsov[2], Mark Hindmarsh[3,4], Kuang Zhang[3,4], Stephan Huber[3], Jeevak Parpia[5], Andrew Casey[1], John Saunders[1]

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Under strong confinement, anisotropic surface pair-breaking dominates the properties of superfluid ^{3}He, favouring chiral ^{3}He-A over time-reversal-invariant ^{3}He-B. Prior experimental extremely sensitive SQUID-NMR studies of ^{3}He in nanofabricated slab-shaped cavities of height D comparable to the size of the Cooper pairs ξ_0 have demonstrated the influence of confinement on the superfluid order parameter, including evidence for a spatially modulated pair-density wave [1]. We have demonstrated - via addition of controlled amount of ^{4}He to coat all the sample surfaces with a ^{4}He film - the tuning of the quasiparticle scattering boundary condition in situ from diffusely scattering to virtually perfectly specular [2]. The latter ensures the survival of ^{3}He-A, with unsuppressed order parameter, down to the quasi-2D limit $D/\xi_0 = 1$ over the full P-T phase diagram. Here we extend such studies to low magnetic fields, decreasing the NMR precession frequency down to 100 kHz instead of 1 MHz used previously. In the absence of ^{4}He surface plating, the potential influence of the magnetic solid ^{3}He boundary layer on the surface pair breaking is of particular interest. We also report progress in using nanofabricated atomically smooth hybrid multi-height cavities for studying the cosmologically relevant A-B phase transition simultaneously in multiple volumes isolated from any bulk liquid and from each other by sufficiently thin regions that will only support ^{3}He-A or normal fluid, depending on boundary conditions.

[1] L. V. Levitin et al., Science **340,** 841 (2013); Phys. Rev. Lett. **111,** 235304 (2013); Phys. Rev. Lett. **122,** 085301 (2019)
[2] P. J. Heikkinen et al., Nat. Commun. **12,** 1574 (2021)

SA2.2 Thermal generation of spin currents in superfluid ^{3}He

Takeshi Mizushima[1], Taiki Matsushita[1], Yusuke Masaki[2], Satoshi Fujimoto[1], Ilya Vekhter[3]

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A new field of research called spin caloritronics has emerged from the discovery of the spin Seebeck effect (SSE) and the spin Nernst effect (SNE). Spin caloritronics has provided new mechanisms for spin-based energy conversion by interconverting spin, charge, and heat. Here we propose exploring spin caloritronics in superfluid 3He in aerogels, where heat current can be converted into spin current via the quasiparticle scattering at nonmagnetic impurities. The thermo-spin conversion phenomena are linked to the symmetry of systems, and using spin caloritronics techniques can serve as direct probes for pairing symmetry and symmetry breaking of superfluids. By analyzing thermo-spin responses through a symmetry-based approach, we find that the combined symmetry of the mirror reflection and two-fold spin rotation prohibits SNE, but the symmetry is spontaneously broken by helical Cooper pairs in the superfluid ^{3}He-B. Using the quasiclassical Keldysh theory, we demonstrate that in the superfluid ^{3}He-B with nonmagnetic impurities, the spin-dependent asymmetric scattering of quasiparticles generates a transverse spin current by the temperature gradient. Both the sign and the magnitude of the SNE sensitively depend on the scattering phase shift at impurity sites. In addition, we find that the SSE can be realized in the A1 phase of the superfluid ^{3}He in aerogels, where nonunitary Cooper pairs spontaneously induce the coupling of spin and heat.

SA2.3 Multiple Phase-Slip Phenomenon in 4He Superflow through a Well-defined Microchannel

Tomoyuki Tani[1], Ryoma Wada[1], Kohei Kaiya[1], Yusuke Nago[1], Satoshi Murakawa[2], **Keiya Shirahama[1]**

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Quantum vortices are significant manifestations of the macroscopic quantum nature of superfluids. Once the system is accelerated in narrow geometries up to a certain critical velocity, a sudden decrease in superfluid velocity corresponding to an immediate change in the phase of the superfluid order parameter, so-called phase slippage, takes place. The phase slip phenomena have been investigated by use of micro-sized apertures, with features explained in the context of generation and motion of quantum vortices [1]. However, the apertures used in the previous experiments were very thin, i.e., their aspect ratios were small.
For the purpose of application to studies of topological superfluid ^{3}He [2], we have developed a micro-slit structure, a well-defined micro-sized channel, in which liquid helium behaves as a quasi-two-dimensional superfluid. The microslit is 2 μm × 100 μm rectangular through-hole with 50 μm depth, much longer than the width. We conducted mass current measurements of superfluid 4He through the microslit with a Helmholtz resonator technique, and successfully observed the phase slip phenomenon. However, the quanta of the phase slippage observed in the measurement showed unexpectedly various values including those much higher than 1. Analyzing the statistics of high-quanta phase slippage occurrence rate and time development of the progress of phase slippage, we found new aspects of the multiple phase slip phenomena, related to dynamics of quantum vortices.

[1] E. Varoquaux, Rev. Mod. Phys. 87, 803 (2015)
[2] T. Kawakami et al., Phys. Rev. B 79, 092506 (2009); T. Mizushima and J. A. Sauls, arXiv:1801.02277 (2018)

SA2.4 Flow of liquid ^{4}He through the membrane containing oriented nanometer-sized channels

Junko Taniguchi, Masato Kuribara, Masaru Suzuki

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In a quasi-one dimension (1D) ^{4}He system, not only the suppression of superfluid growth, but also the behavior of critical velocity has attracted great interest.[1,2] One of the most interesting questions is what happens when the channel diameter is decreased close to the coherence length. Recently, the prediction that the critical velocity will drastically drop due to the decrease in the energy barrier for the nucleation of the vortex line has been reported. We have started the measurements of the flow of liquid ^{4}He through the bundle of straight uniform 3.4-nm channels synthesized in a porous alumina membrane. Under 0.13 MPa, the mass velocity shows a rise at around 1.5 K, at which superfluid growth in the channel is observed by the torsional oscillator technique. From the magnitude of the rise, the velocity of superflow is evaluated as at most in the order of 10^{-1} m s^{-1}, which is nearly two digits smaller than the value which was previously reported for a single 6.3-nm hole.[1] This small superfluid velocity supports the above theoretical prediction. We have also observed the rise in the velocity at 2.15 K, just below the superfluid transition temperature of bulk ^{4}He. This observation is surprising since the normal fluid fraction has been thought to be locked to the channel wall in such narrow channels and suggests an unknown mechanism of normal flow.

[1] P. Duc et al., Sci. Adv. 1, e1400222 (2015).
[2] A. Del Maestro et al., Phys. Rev. B 95, 140507R (2017).

SA3.1 Single electrons on solid neon: a long-coherence high-fidelity solid-state qubit platform

Xianjing Zhou[1,2], Xinhao Li[1], Qianfan Chen[1], Gerwin Koolstra[3], Ge Yang[4], Brennan Dizdar[5], Xu Han[1,2], Xufeng Zhang[6], David Schuster[2,5,7], **Dafei Jin[1,2,8]**

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Progress towards the realization of quantum computers requires persistent advances in their constituent building blocks – qubits. Novel qubit platforms that simultaneously embody long coherence, fast operation, high fidelity, and large connectivity offer compelling advantages in the construction of quantum computers. In this talk, I will present our experimental realization of a new qubit platform based upon isolated single electrons trapped on an ultraclean solid neon surface in vacuum. By integrating an electron trap in a superconducting quantum circuit, we achieve strong coupling between the charge states of a single electron and a single microwave photon in an on-chip resonator [1]. Qubit gate operations and dispersive readout are successfully implemented. The measured relaxation time T1 and coherence time T2 are both on the order of 0.1 milliseconds [2]. The single-shot readout fidelity without relying on a quantum-limited amplifier is 98.1%. The average single-qubit gate fidelity using Clifford-based randomized benchmarking is 99.97%. Simultaneous strong coupling of two qubits with the same resonator is demonstrated, as a first step toward two-qubit entangling gates for universal quantum computing. These results manifest that the electron-on-solid-neon (eNe) charge qubits outperform all existing charge qubits to date and rival state-of-the-art superconducting transmon qubits, offering an appealing platform for quantum computing.

[1] X. Zhou et al., Nature 605, 46–50 (2022). [2] X. Zhou et al., arXiv:2210.12337 (2022).

SA3.2 Rydberg-state detection for electrons-on-helium qubits

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The spin of electrons trapped on the surface of liquid helium presents a promising resource for quantum computing. However, spin control is a challenging problem. Recently, we proposed a hybrid quantum computer that utilizes the spin-orbit coupling between spin and the Rydberg states of the electron quantized motion perpendicular to the surface [1]. In this proposal, a quantum-non-demolition readout of the spin state can be accomplished by detecting the spin-selective Rydberg transition. We also proposed a sensitive image-charge method to detect the Rydberg transition, as was successfully realized for a many-electron system [2]. To scale it down to the detection of a single-electron transition we are developing two charge-sensitive methods. The first method is based on the image-current amplification by a high-impedance superconducting resonator. With this method, we currently achieve sensitivity of 2.3 fA per square root Hz, which should allow us to detect the single-electron Rydberg transition in about 0.2 s measurement time. The second method is based on a dispersive readout of the Rydberg transition using a resonant LC circuit. A small change in the circuit capacitance induced by the Rydberg transition of electrons is monitored by the RF power reflected from the circuit. With this method, we currently achieve sensitivity of about 0.1 aF per square root Hz. This would allow us to read out the state of a qubit in a measurement bandwidth of about 0.3 MHz, which is crucial for building high-fidelity qubit gates [1].

[1] E. Kawakami et al. arXiv:2303.03688.
[2] E. Kawakami et al. Phys. Rev. Lett. 126, 106802 (2021); S. Zoe and D. Konstantinov, New J. Phys. 24, 103026 (2022).

SA3.3 High-frequency collective dynamics of electrons on helium

Johannes Pollanen

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Electrons floating above the surface of superfluid helium form a unique platform for studying the high-frequency collective dynamics of ultra-high mobility trapped electrons. In this talk I will describe our recent experiments investigating novel high-frequency many-electron phenomena in this system. The electrons are simultaneously subjected to microchannel confinement and coupled to microwave frequency photons or piezophonons, which are used to excite collective excitations of the electron system. The microchannel devices provides precision spatial control of the electrons and enable access to both quasi-one-dimensional electron chains as well as two-dimensional electron sheets. Additionally, by subjected the electrons to RF-frequency driving fields we are able to reveal resonant behavior of the confined electrons associated with their wave-like transport nature, which we discuss as potentially arising from their collective inertial response.

SA3.4 Stability and Dynamics of Multielectron Bubbles in Liquid Helium

Ambarish Ghosh

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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. I will discuss some of our recent results pertaining to the motion, stability and electronic structure of the MEBs. Using time varying electric fields, it has been possible to excite their resonant modes, which suggests a new way of investigating these interesting objects. We will mention the conditions under which the bubbles can be rendered stable over a long duration, either in bulk or held against a metallic substrate, and discuss ways to determine the phase of the electron layer inside the bubbles.

SA4.1 Quantum gas in a box

Zoran Hadzibabic

Cavendish Lab, University of Cambridge, Cambridge, UK

For nearly three decades ultracold atomic gases have been used with great success to study fundamental many-body phenomena such as Bose-Einstein condensation and superfluidity. While traditionally they were produced in harmonic electromagnetic traps and thus had inhomogeneous densities, it is now also possible to create homogeneous samples in the uniform potential of an optical box trap [1]. Box trapping simplifies the interpretation of experimental results, provides more direct connections with theory and, in some cases, allows qualitatively new, hitherto impossible experiments. I will give an overview of our recent experiments with box-trapped three- and two-dimensional Bose gases, focusing on a series of related experiments on far-from-equilibrium phenomena, including turbulence [2-4] and dynamic scaling in driven disordered gases [5].

[1] Quantum gases in optical boxes (review), N. Navon, R. P. Smith, and Z. Hadzibabic, Nat. Phys. **17**, 1334 (2021).
[2] Emergence of a turbulent cascade in a quantum gas, N. Navon, A. L. Gaunt, R. P. Smith, and Z. Hadzibabic, Nature **539**, 72 (2016).
[3] Emergence of isotropy and dynamic scaling in 2D wave turbulence in a homogeneous Bose gas, M. Galka et al., Phys. Rev. Lett. **129**, 190402 (2022).
[4] Universal equation of state for wave turbulence in a quantum gas, L. H. Dogra et al., arXiv:2212.08652
[5] Observation of subdiffusive dynamic scaling in a driven and disordered box-trapped Bose gas, G. Martirosyan et al., arXiv:2304.06697

SA4.2 Turbulent steady states in Bose-Einstein condensates

Giorgio Krstulovic

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Quantum turbulence is a phenomenon characterised by the interaction of nonlinear waves and quantum vortices. When forcing and dissipation act on well-separated scales in such systems, out-of-equilibrium steady states are characterised by the emergence of turbulent cascades analogously to classical hydrodynamics. These turbulent cascades are responsible for energy and particle transfers along different wave numbers. In the absence of vortices, wave interaction is weak, and the formalism of weak wave turbulence can be applied to the Gross-Pitaevskii (GP) equation to obtain analytical predictions.

In this talk, I will first present some recent analytical results on 3D turbulent Bose-Einstein condensates (BEC). Our new predictions explain previous experimental observations reporting an anomalous exponent in the case of the direct energy cascade and completely determine the inverse particle cascade. Our results also provide the analytical values of the universal proportionality prefactors. Then, I will discuss 2D turbulent BECs in the case where acoustic waves (phonons) dominate. I will present a new theory for 2D BECs, allowing us to determine the energy spectrum completely in this mathematically singular case. All our results are validated by using high-numerical simulations of the GP equation and its associated wave-kinetic equation. We find an excellent agreement between data, the predicted scaling exponents, and the universal prefactors without any adjustable parameters.

SA4.3 HVBK equation-based theory of developed counterflow superfluid turbulence

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[2]Mathematics, Rensselaer Polytechnic Institute, Troy, NY,USA
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[4]Chemical and Biological Physics, Weizmann Institute of Sciences, Rehovot, Israel

Based on the Hall-Vinen-Becharevich-Khalatnikov coarse-grained hydrodynamic equations of the two-fluid model of superfluids He-4 we develop a theory of the energy spectra in the thermally driven turbulent counterflow. The key ingredients of the theory are the three-dimensional differential closure for the vector of the energy flux and the anisotropy of the mutual friction force. We suggest an approximate analytic solution of the resulting energy-rate equation, which is fully supported by our numerical solution. The two-dimensional energy spectrum is strongly confined in the direction of the counterflow velocity. In agreement with the experiments, the energy spectra in the direction orthogonal to the counterflow exhibit two scaling ranges: a near-classical non-universal cascade-dominated range and a universal critical regime at large wavenumbers. The theory predicts the dependence of various details of the spectra and the transition to the universal critical regime on the flow parameters.

SA4.4 Drag force due to quantum viscosity in superfluid ^{4}He at zero temperature

Hiromitsu Takeuchi

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Reynolds similitude, a key concept in hydrodynamics, states that two phenomena of different length scales with a similar geometry are physically identical. Flow properties are universally determined in a unified way in terms of the Reynolds number R (dimensionless, ratio of inertial to viscous forces in incompressible fluids). For example, the drag coefficient c_D of objects with similar shapes moving in fluids is expressed by a universal function of R. Certain studies introduced similar dimensionless numbers, that is, the superfluid Reynolds number R_S, to characterize turbulent flows in pure superfluids at zero temperature. However, the applicability of the similitude to inviscid quantum fluids is nontrivial as the original theory is applicable to viscous fluids and the microscopic mechanism of dissipation in pure superfluids has not been established quantitatively. This study proposed a method to verify the similitude using current experimental techniques in quantum liquid He-II [1]. A precise relation between c_D and R_S was obtained in terms of the terminal speed of a macroscopic body falling in He-II by taking account the contribution from the normal component as a thermal correction at finite temperatures across the Knudsen (ballistic) and hydrodynamic regimes of bosonic quasiparticles. Reynolds similitude in superfluids can facilitate unified mutual development of classical and quantum hydrodynamics.

[1] Hiromitsu Takeuchi, *Quantum viscosity and the Reynolds similitude in quantum liquid He-II*, arXiv:2302.07039 (2023)

4.6 Poster Presentations: Saturday 12th August

SA5.1 **Electromagnetic Response of Superconducting Cavities**

Mehdi Zarea, Hikaru Ueki, James Sauls

Hearne Institute of Theoretical Physics, Department of Physics and Astronomy, Louisiana State University

We present results based on the nonequilibrium dynamical equations [1] for doped Niobium SRF cavities driven for out of equilibrium by the resonant microwave field [2]. We report calculations of the frequency shift, and quality factor, as a function of temperature and the electron-impurity scattering rate. The calculated bulk superconducting current response [1], combined with the appropriate boundary conditions for the current and EM fields at the vacuum-metal interface, accurately predicts the observed frequency shifts of order a fraction of a Hz over the temperature range $0 < T \leq T_c$, including the frequency anomalies observed near T_c in Niobium SRF cavities [2]. Results for the complex current response function for temperatures near T_c provide additional insight into the origin of the anomalous frequency shift in the form of a scaling formula for the dependence of the frequency shift on the impurity scattering rate, resonance frequency and temperature. Calculations of the frequency shift and quality factor, as well as the suppression of T_c by disorder [3], provide new analysis tools for characterizing disorder in SRF cavities for both accelerator applications as well as detector applications.

Supported by NSF Grant PHY-1734332 and DE-AC02-07CH11359

[1] D. Rainer and J. A. Sauls, World Scientific, Singapore, 1994, Chap.2, pp. 45–78.
[2] D. Bafia, A. Grassellino, M. Checchin, J. Zasadzinski, and A. Romanenko, e-print arXiv:2103.10601 (2021).
[3] M. Zarea, H. Ueki, and J. Sauls, arXiv preprint arXiv:2201.07403 (2022).

SA5.2 **Electron teleportation in Kitaev wire with Coulomb interaction**

Mehdi Zarea[1], Ivar Martin[2], **James Sauls[1]**

[1]Hearne Chair of Theoretical Physics, Department of Physics and Astronomy, Louisiana State University, Baton Rouge, USA
[2]Material Science Division, Argonne National Lab, Chicago, USA

We study the problem of electron teleportation in a *p*-wave superconducting wire [1] as a function of the Coulomb interaction strength. We calculate the change in the probability $\Delta\rho$ of finding an electron at one edge of the wire when another electron is injected at the other edge site.

In the absence of Coulomb interaction there is no change in this probability. Including the global charging energy for the wire [2] makes $\Delta\rho$ finite but length-dependent, tending to zero with increasing wire length.

We also investigate a modified model in which the Coulomb charging energy is included only between the two edge sites. For this model the change in the probability becomes length-independent. However, unlike the canonical spin-teleportation i) this effect is transient (time-dependent) ii) it relies on existence of instantaneous Coulomb correlation between edge sites iii) the value of $\Delta\rho$ is lower than the corresponding normal metal wire.

These limitations argue for impossibility of teleportation via Majorana fermions even in the presence of Coulomb interactions.

[1] G. W. Semenoff and P. Sodano, arXiv preprint cond-mat/0605147 (2006)
[2] L. Fu, Physical Review Letters 104, 056402 (2010)

SA5.3 **Is $YbRh_2Si_2$ a Spin-Triplet Superconductor?**

James Sauls

Hearne Institute of Theoretical Physics, Louisiana State University, Baton Rouge, LA, USA

The Royal Holloway ULT group has measured resistive transitions in $YbRh_2Si_2$ below 10 mK and found four transitions as a function of temperature and magnetic field, some exhibiting Pauli limiting and others exhibiting only diamagnetic pair breaking, suggesting the possibility of multiple superconducting phases belonging to one or more odd-parity spin-triplet representations. I report analysis of the possible phases, and phase diagram, based on odd-parity, spin-triplet pairing in the presence of symmetry breaking fields originating from pre-existing AFM order and strain.

SA5.4 **Determination of complex conductivity of superconducting YbRh2Si2 by measurements of low frequency ac magnetic susceptibility.**

Petra Knappova[1], Marijn Lucas[1], Lev Levitin[1], Jan Knapp[1], Andrew Casey[1], Kristin Kliemt[2], Cornelius Krellner[2], Manuel Brando[3], Brian Cowan[1], **John Saunders[1]**

[1]Department of Physics, Royal Holloway University of London, Egham, UK
[2]Physikalisches Institute, Goethe University, Frankfurt, Germany
[3]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

The heavy fermion metal YbRh2Si2 is superconducting below around 10 mK, and is a candidate odd parity, and hence topological, superconductor. Our 4-terminal electrical transport study of a number of samples demonstrates the important role played by sample inhomogeneity in the measured response.

Here we report measurements of the ac susceptibility at frequencies < 1 kHz, on a slab-like sample 380μm thick, to determine the complex conductivity of the superconducting state. The sample is magnetically shielded to around 20 nT, and studied as a function of magnetic field applied perpendicular to the c-axis.

As a first step, we simply analyse the results in terms of an effective London penetration depth λ. The effective λ shows an unusual temperature dependence with a significantly larger effective $\lambda(T=0)$ than anticipated, supporting inhomogeneous superconductivity. On cooling a distinct downward step in λ clearly shows a transition into a new superconducting regime at TA ~ 2 mK, coinciding with a sharp heat capacity signature and by a drop in sample inductance seen in electrical transport. Since the onset of more robust superconductivity, below TA in zero field, is associated with a new SDW antiferromagnetic order, it is a candidate odd-parity PDW.

We will also report the strong field dependence of the complex conductivity in the context of non-linear Meissner effect, and discuss evidence for line nodes in the gap structure, and topological surface states. A better analysis of the influence of sample inhomogeneity on the analysis of complex ac magnetic susceptibility is a future goal.

SA5.5 Electrical transport study of unconventional superconductivity in $YbRh_2Si_2$

Lev Levitin[1], Jan Knapp[1], Marijn Lucas[1], Petra Knappova[1], Jan Nyeki[1], Brian Cowan[1], Andrew Casey[1], Kristin Kliemt[2], Cornelius Krellner[2], Manuel Brando[3], Christoph Geibel[3], John Saunders[1]

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[2]Physikalisches Institut, Goethe University, Frankfurt am Main, Germany
[3]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

We present the study of interplay between magnetism and superconductivity in a heavy-fermion metal $YbRh_2Si_2$, probed with high-resolution measurements of electrical impedance down to 0.2 mK. Simultaneously our SQUID-based technique infers the contact impedance, including regions of the sample close to the voltage probes. Additionally it doubles as a sample noise thermometer and can observe quantised persistent currents in a loop comprised of $YbRh_2Si_2$ and conventional superconductors.

$YbRh_2Si_2$ hosts two antiferromagnetic phases, AFM1 and AFM2 with critical temperatures T_N = 70 mK and T_A = 1.5 mK. The superconductivity manifests below 10 mK on the background of AFM1 and AFM2 as zero resistance or a partial resistance drop. Simultaneously the imaginary part of the sample impedance develops, that we attribute to the kinetic inductance. The sample-to-sample variation reveals strong inhomogeneities in the superconducting order. This is further supported by the frequency dependence of the impedance at 3-10000 Hz.

Rich superconducting phase diagrams emerge in magnetic fields applied in *ab* plane and along *c* axis of the tetragonal $YbRh_2Si_2$, revealing multiple responses of superconductivity to the field, including linear (orbital) and quadratic (Pauli) suppression, and non-monotonic behaviour. We attribute these to distinct pairing states with different spin structures.

Importantly, in every sample the superconductivity is switched off at the critical field of AFM1; moreover the impedance abruptly changes across the AFM1-AFM2 phase boundary. We conclude that the superconducting order parameters in YbRh2Si2 are sensitive to the magnetic state and require the AFM order. An intriguing scenario is spin-triplet pairing mediated by ferromagnetic fluctuations.

SA5.6 Higher Landau level vortex state realized in superconducting FeSe

Ryusuke Ikeda

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Recent transport measurements in iron-selenides (FeSe) in high magnetic fields and at lower temperatures have shown the presence of some kind of spatially modulated vortex lattice or glass phase. The shrinkage of the fluctuation-induced vortex liquid region at intermediate temperatures characteristic of this superconducting material implies that this novel phase is induced by the paramagnetic pair-breaking. Then, one might wonder if this high field superconducting phase is a kind of Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) phase realized as a vortex solid.

By focusing on the characteristic negative magneto-resistance behavior and an insulating behavior in the resistivity data in the fluctuation regime, we argue that the novel superconducting phase must be the second-lowest Landau level vortex phase in which the vortices show a stripe pattern of the Cooper-pair field (superconducting order parameter). Numerical study on the vortex states to be realized in the higher Landau level state of the superconducting order parameter is in progress.

SA5.7 Effect of different mutual friction models on velocity fluctuation of normal-fluid in superfluid helium-4

Hiromichi Kobayashi[1], Satoshi Yui[2], Makoto Tsubota[2]

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In superfluid helium-4, a quantized vortex affects normal-fluid via mutual friction. An empirical model for mutual friction has been proposed by Schwarz [1] and has been used for two-way coupled simulations, e.g., see Ref. [2]. Recently, a self-consistent model [3] has been proposed. In the model, the theoretical friction force by a vortex line is adopted, so that there is no empirical parameter determined by experiments. The time evolutions of the vortex ring radius for the two models have been compared with experimental results, and it was revealed that the self-consistent model yields better agreement with experimental results than the empirical model [4]. In this study, we compared the effect of the two models on the velocity fluctuation of normal-fluid. In the cases of the vortex ring and reconnection events, there is a difference in the location of normal-fluid vortex tubes and the energy transfer from superfluid to normal-fluid, whereas there is little difference in the probability density function (pdf) of superfluid and normal-fluid. In the case of thermal counterflow, there is little difference in the pdf, while the self-consistent model predicts a little larger velocity fluctuation than the empirical model.

[[1] K. W. Schwarz, Phys. Rev. B 31, 5782 (1985).
[2] S. Yui, H. Kobayashi, M. Tsubota, W. Guo, Phys. Rev. Lett. 124, 155301 (2020).
[3] L. Galantucci, A. W. Baggaley, C. F. Barenghi, G. Krstulovic, Eur. Phys. J. Plus 135, 547 (2020).
[4] Y. Tang, W. Guo, H. Kobayashi, S. Yui, M. Tsubota, T. Kanai, arXiv:2211.01560 (2022)

SA5.8 Cascade and isotropization of momentum distribution of turbulence in two-component Bose-Einstein condensates

Issei Doki[1], Yuto Sano[2], Makoto Tsubota[1]

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[2]Physics, Osaka City University, Osaka, Japan

It is difficult to reproduce and predict turbulent dynamics because of its non-linearity. However, statistical behaviors such as Kolmogorov law and turbulent cascade have been studied because they are reproducible. Navon et al. realized quantum turbulence in Bose-Einstein condensate (BEC) trapped by a cylindrical box potential by driving it with an oscillating force [1, 2]. They observed direct cascade and isotropization of the momentum distribution experimentally. The cascade was also confirmed by numerical simulation of the Gross-Pitaevkii (GP) model. Moreover, Sano et al. investigated numerically the details of the anisotropy of the momentum distribution in the same system and found that the isotropy was restored from low toward high wavenumbers in spite of the anisotropic energy injection [3]. The cascade and anisotropy of momentum distribution in the turbulence of two-component BECs have not yet been studied. We numerically study turbulence in two component BECs and reveal how the cascade and anisotropy of momentum distribution depend on the coupling constants.

[1] Navon et al., Nature 539, 72 (2016).
[2] Navon et al., Science 366, 382 (2019).
[3] Sano et al., EPL 140, 66002 (2022).

SA5.9 **Rotating turbulence in Bose-Einstein Condensates**

Yuto Sano[1], Makoto Tsubota[2]

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Rotating turbulent flow is a common occurrence in nature, and the presence of rotation gives a characteristic behavior not found in isotropic turbulence. One such behavior is anisotropic energy transfer due to the Coriolis force, which causes a coherent structure of turbulence around the rotation axis and makes three-dimensional turbulence two-dimensional [1].

Recently, decaying rotating turbulence in Bose-Einstein condensates (BECs) has been studied numerically by Estrada *et al*. [2,3]. They found a characteristic power law k^{-1} in the incompressible kinetic energy spectrum at the smaller length scale than the intervortex distance and anisotropic sound emissions. However, a statistically steady state of quantum rotating turbulence has not been adequately studied.

Therefore, we studied forced-decay rotating turbulence in a weakly elliptical harmonic trap by numerically solving the Gross-Pitaevskii (GP) equation and found statistically steady rotating turbulence shows k^{-1} scaling in the incompressible kinetic energy spectrum. This power law behavior is consistent with the previous results of decaying rotating turbulence. We also uncovered that the power law of wave turbulence theory could be observed in the wavenumbers where the effect of rotation term in the GP model is small compared with the kinetic energy.

[1] C. Morize, F. Moisy, and M. Rabaud, *Phys. Fluid*, **17**, 095105 (2005).
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[3] J. A. Estrada, M. E. Brachet, and P. D. Mininni, *AVS Quantum Science*, **4**, 046201 (2022).

SA5.10 **Vortex-filament bundle induced by normal-fluid turbulence in turbulent superfluid helium-4**

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In superfluid helium-4, there are two forms of quantum turbulence. One is the Quasi-Classical Turbulence (QCT), and the other is the ultra-quantum turbulence (or Vinen turbulence). In the QCT, a bundle structure of vortex filaments is believed to be formed to mimic the normal-fluid vortices. To elucidate such a vortex-bundle formation and physics of QCT, we should consider the coupled dynamics of quantum turbulence and normal-fluid turbulence. However, in preceding studies, the 2-way coupled dynamics of the QCT has not been uncovered yet, although the 1-way coupled dynamics was studied [1]. Thus, we study the 2-way coupled dynamics of quantum turbulence and normal-fluid turbulence to investigate the formation of the vortex-filament bundle. The method is the coupled simulation of the vortex filament model and Navier-Stokes equations for the normal fluid [2]. Here, the normal-fluid turbulence is driven by an external forcing. Because such a simulation needs high computational costs, we employ the fast multipole method for the vortex filament model. First, we perform the simulation without mean counterflow velocity. As a result, we obtained the quantum turbulence in which vortex-filament bundles are formed due to the mutual friction with the normal-fluid turbulence. Second, we simulate the case of thermal counterflow. In this case, the applied counterflow breaks the bundles and entangles the filaments, i.e., Vinen turbulence appears.

[1] J. Laurie and A.W. Baggaley, Phys. Rev. Fluids 8, 054604 (2023).
[2] S. Yui et al., Phys. Rev. Lett. 124, 155301 (2020).

SA5.11 **Universal defect density scaling in an oscillating dynamic phase transition**

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The Kibble-Zurek mechanism (KZM) is a fundamental theory with universal applicability in continuous phase transitions. When a system undergoes a smooth transition from a disordered phase to an ordered phase, topological defects with long lifetimes spontaneously emerge. A specific relationship between the critical exponent of the phase transition and the defect density is also revealed that $\rho_{KZ} \sim \tau^{\frac{\nu}{1+\nu z}}$. KZM has been widely verified in numerical simulations and experiments on equilibrium systems, and has recently been extended to non-equilibrium systems, such as polaron BKT phase transitions and absorption phase transitions, indicating its universality in non-equilibrium systems.

Here, we investigate the KZM in a unique non-equilibrium system: an oscillating dynamic phase transition. In a holographic superconductor (superfluid) system, an oscillating electric field is introduced, and when the field is strong enough, a phase transition spontaneously occurs, causing the system to transition from an ordered phase to a disordered phase and vice versa. Therefore, when the field strength is linearly decreased from a large field strength above a critical point, and the system smoothly crosses the phase transition point, the Kibble-Zurek mechanism occurs, and vortices appear in the system. We demonstrate that the relationship between the number of vortices and the quenching rate satisfies the KZM and the critical exponent.

At the same time, we also confirm the power law of fast quenching beyond the KZM that $N \sim \epsilon^{dz}$. We conclude that the KZM is also applicable to non-equilibrium systems with dynamic phase transitions, and that such non-equilibrium phase transitions can be easily verified in experiments.

SA5.12 **Dynamics of pinned quantized vortices in superfluid ^{4}He in microelectromechanical oscillator**

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Vortex pinning is an important issue in condensed matter systems. It is realized in superfluid helium, superconductors and a neutron star etc. In superfluid ^{4}He, the pinning comes from surface roughness of solid boundaries, and have been treated as a key to reveal various physics such as phase slip phenomena [1] and dissipation [2]. The experimental group of University of Florida found that the pinning could be related to the damping of a microelectromechanical oscillator [3]. In this study, we model the vortex pinning and describe the vortex dynamics with pinning to reveal the experimental picture related to the pinning. We propose two models; (i) Critical angle model and (ii) Hemispherical pinning site model. In (i) Critical angle model, we assume extremely rough surface on boundaries. The edge of vortex is fixed on a boundary forcibly and depinning is described by introducing a critical angle. In (ii) Hemispherical pinning site model, pinning is described by solving boundary condition on a hemispherical bump.

We discuss the experimental observation using these two models. In our model (i), the energy of the vortex is dissipated by repeating reconnection with bumps on the solid boundaries with complicated surface even at 0 K. As the result, turbulence generation is suppressed by the roughness. This can explain the experimental picture well. Also, we study depinning and the dynamics near the rough boundary in the model (ii).

[1] W. I. Glaberson and R. J. Donnelly, Phys. Rev. **141** 208 (1966)
[2] R. J. Zieve *et al*., Phys. Rev. B **84** 174504 (2012)
[3] C. S. Barquist *et al*., Phys. Rev. B **101** 174513 (2020)

SA5.13 Isolated fractional skyrmions generated by Kelvin-Helmholtz instability in a magnetic quantum gas

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Spinful superfluids of ultracold atoms are ideal for investigating the intrinsic properties of spin current and texture because they are realized in an isolated, non-dissipative system free from impurities, dislocations, and thermal fluctuations. This study theoretically reveals the impact of spin current on a magnetic domain wall in spinful superfluids [1]. An exact wall solution is obtained in the ferromagnetic phase of a spin-1 Bose-Einstein condensate of ^{7}Li atoms with easy-axis anisotropy at zero temperature. The bosonic-quasiparticle mechanics analytically show that the spin current along the wall becomes unstable if the velocity exceeds the critical spin-current velocities, leading to complicated situations because of the competition between transverse magnons and ripplons. Our direct numerical simulation reveals that quantum Kelvin-Helmholtz instability [2] generates an eccentric fractional skyrmion, which has a fractional topological charge, but its texture is not similar to that of a meron.

[1] Hiromitsu Takeuchi, *Spin-current instability at a magnetic domain wall in a ferromagnetic superfluid: A generation mechanism of eccentric fractional skyrmions,* Physical Review A 105, 013328 (2022)
[2] Haruya Kokubo, Kenichi Kasamatsu, and Hiromitsu Takeuchi, *Pattern formation of quantum Kelvin-Helmholtz instability in binary superfluids,* Physical Review A 104, 023312 (2021)

SA5.14 Critical velocity for quantized vortex formation in a superfluid wake with a plate obstacle

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A wake generated by an object moving through a fluid depends on the size and velocity of the obstacle, being associated with various physical phenomena such as vortex formation and turbulent transition. Wake phenomena have been also studied experimentally and theoretically in superfluids. In cold atomic Bose-condensed systems, optical potentials have been used in superfluid wake experiments [1,2]. In numerical simulations [3,4], a Gaussian potential is often assumed as obstacles. However, the dynamics of the wake and the critical velocity for vortex formation depend on the quantitative details of the obstacle potential, which prohibits the universal discussion. A plate obstacle is comparatively easy to handle both theoretically and numerically. The size of the obstacle can be characterized only by the width of the plate, making it easy to study its effects. In this study, the size dependence of the critical velocity for quantum vortex formulation in the wake of a 2D Bose-Einstein condensate with the plate obstacle is investigated.

[1] W.J. Kwon, J.H. Kim, S.W. Seo, and Y. Shin, Phys. Rev. Lett. 117, 245301 (2016)
[2] Y. Lim, et al, New J. Phys. 24, 083020 (2022)
[3] K. Sasaki, N. Suzuki, and H. Saito, Phys. Rev. Lett. 104, 150404 (2010)
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SA5.15 Non-equilibrium Dynamics of Vortices in Two-Dimensional Quantum Fluids

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A gas of bosonic atoms cooled to ultracold temperatures will undergo a transition to the superfluid phase. If a two-dimensional gas is quenched rapidly through this transition, it initially forms a disordered system of quantised vortices and antivortices, before relaxing towards a uniform equilibrium state via vortex-antivortex annihilation. Recent simulations of this process, using the Gross-Pitaevskii equation, provide strong evidence of universal scaling, with values of the dynamical critical exponent close to two and dependent upon dissipation. However, questions remain as to how this value is linked to the motion, and annihilation, of vortices in the two-dimensional gas. Here I present the results of large-scale simulations, using the classical point vortex model, for a system of over 4000 vortices and antivortices. I explore a wide range of dissipations and initial vortex configurations and map out the dependence of the dynamical critical exponent upon each.

SA5.16 Energy and Helicity Transfer in Superfluid Helium

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Helicity is an invaluable, global measure of classical flows, characterizing the knottedness of vortex lines. In turbulence, helicity dictates the non-linearity of the governing Navier-Stokes equation, restricting the energy cascade mechanism; in astrophysics it also quantifies the breaking of reflectional symmetry, particularly in the generation of magnetic fields by dynamo action.

In the last years, a lively debate has characterised the definition and the role of helicity in superfluids, where vorticity is truly confined to one-dimensional vortex lines (unlike classical viscous fluids where vortex lines are an idealisation) evolving in an inviscid background; unlike the classical ideal context (where changes of the topology are prevented by the Helmholtz theorem), quantised vortex lines can reconnect upon collisions. Recently, a quantitative model of superfluid helicity at mesoscopic length scales has been successful in distinguishing different turbulent regimes.

However until now, the coupling of helicity and energy in both superfluid and normal fluid components of helium II has not been explored. In a simple, non-turbulent system, here we study the damping of a superfluid Kelvin-wave in an initially quiescent normal fluid, evolving self-consistently both the superfluid vortices and the normal fluid component. In this way, we can track the transfer of energy and helicity from one component to the other. Initially, the superfluid Kelvin-wave injects energy and helicity in the normal fluid via the mutual friction force, after which the normal fluid viscous dissipation becomes predominant, ultimately dissipating helical normal motion.

SA5.17 **Stability of quantised vortices in two-component condensates**

Sam Patrick[1], Ansh Gupta[1], Ruth Gregory[1,2], Carlo F Barenghi[3]

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In Bose-Einstein condensates comprising a single species of atoms, large quantum vortices are prone to decay into clusters of smaller vortices. However, by placing a small amount of atoms of a second species inside the vortex cores, it is possible to prevent this decay and stabilise large quantum vortices. The mechanism behind the instability is the same one that leads to superradiance around rotating black holes. I will show how this perspective leads to an intuitive interpretation of the stabilisation mechanism. I will also present some interesting consequences of the stabilisation, such as the counter-rotation of a pair of corotating vortices.

SA5.18 **Diffusion of vortex tangle in a narrow tube due to thermal counter-flow**

Ken Obara, Satsuki Yoshisaka, Hideo Yano, Osamu Ishikawa

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Thermal counterflow in superfluid helium has been known as a test field to study quantum turbulence. One of the most prominent works is the discovery of the TI-to-TII transition studied by Martin and Tough [Phys. Rev. B 27, 2788 (1983)]. Now a day, it is widely believed that TI-to-TII transition is associated with an instability in the laminar flow of the normal fluid. Up to now, most of the experimental works have been treated the quantum turbulence in bulk space. Our apparatus consisted of two bulk chambers, named chamber A and B, connected with a narrow tube whose diameter was 0.25 mm and its length was 8 mm. The second resonators were mounted in each of the two chambers to measure the vortex line densities. At T = 1.65 K, we found that when a heat pulse exceeding a certain threshold power was applied to chamber A, quantum turbulence appeared in both chambers. Here, the superfluid flew from chamber B to A. We also found that the vortex line densities in the chamber B were always higher than that of chamber A, revealing that the quantum turbulence in the tube diffused in both directions, but in the sufficiently high thermal counter flow, it was swept not by the superfluid flow but normal fluid flow. This result is consistent with our vortex-loop time-of-flight experiment under relatively high thermal counterflow, but the reason for this anisotropy is not yet clear.

SA5.19 Vortex Emission from Counter Flow Turbulence in Superfluid Helium 4

Yoma Miyakoda, **Ken Obara**, Hideo Yano

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We report the vortex emission of counter flow turbulence produced in a narrow channel in superfluid helium. In a channel, vortex lines emerge in thermal counter flow above a critical velocity. We generated turbulence in a circular channel with an inner diameter of 0.3 mm by thermal counter flow to study the emission of vortex rings detected by a vibrating wire mounted outside on the axis of the channel. Since a superfluid vortex tends to move on a superfluid flow, emissions of vortex rings are observable outside the channel when the superfluid flows out. In the opposite direction, the emission is likely to reduce considerably, though we observed higher detection rate of vortex rings for the opposite flow. This behavior suggests that vortex rings can move against the superfluid flow in a counter flow.

SA5.20 Radial thermal counter flow in superfluid ^{4}He studied by means of a quartz tuning fork

R.-Z. Wei[1], Y.-X. Wu[1], J.-H. Lee[1], Q.-Y. Zhou[1], B.-L. Young[1], W.-B. Jian[1], **K. Kono[2]**

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This is a progress report on a radial thermal counter flow produced by a heated small tungsten filament immersed in superfluid ^{4}He and probed by means of quartz tuning fork. It is an open geometry experiment inside a He bath, which is directly pumped. In this configuration, there is no solid wall parallel to the counter flow, unlike the popular duct geometry.

There is a heating power threshold to form a bubble around the filament. The preliminary measurement shows a prominent increase in fluctuations of a tuning fork signal after the bubble formation. The appearance of fluctuations depends on the existence of bubble, but not on the heating power, which in turn is directly related to the magnitude of the counter flow. Therefore, the fluctuations may not be due to the quantum turbulence. In this report, we discuss about the origin of fluctuations.

SA5.21 Vibrating micro-wire resonators used as a local probe of quantum turbulence in superfluid ^{4}He

Šimon Midlik, Maximilián Goleňa, Marek Talíř, David Schmoranzer

Department of Low-Temperature Physics, Charles University, Prague, Czech Republic

We present the use of 60 µm thick superconducting NbTi vibrating wire resonator as a local probe of quantum turbulence in superfluid ^{4}He (He II). Wire resonance is driven via magneto-motive force, exclusively in laminar hydrodynamic regime. For the detection of quantized vortices, changes in the probe resonant frequency and peak amplitude are measured in reaction to the applied external counterflow. Calibration of the device response is obtained in thermal counterflow in the temperature range from 1.45 K to 2.1 K against second sound attenuation data. The main motivation of this work is the development of local probes of quantum turbulence suitable for use in non-homogeneous systems such as flows with spherical or cylindrical symmetry. The frequency response of the devices is described with good accuracy at lower temperatures by considering the balance between viscosity and mutual friction and its effect on the boundary layer. Under the experimental conditions, the fluid-structure interaction cannot be modeled reliably by an effective turbulent viscosity and agrees better with a model of the boundary layer modified by mutual friction. The obtained results may be extended to the interaction of nanoscale devices with sufficiently dense vortex tangles.

SA5.22 Shaking and Stirring Helium-4 with a Superconducting Levitating Probe

M. Arrayás[1], F. Bettsworth[2], C.C.E. Elmy[2], D. Field[2], RP Haley[2], R. Schanen[2], D.E. Smart[2], S. Soulerin[2,3], J.L. Trueba[1], C. Uriarte[1], V.V. Zavjalov[2], D.E. Zmeev[2]

[1]Area de Electromagnetismo, Universidad Rey Juan Carlos, Madrid, Spain
[2]Department of Physics, Lancaster University, Lancaster, United Kingdom
[3]Filiere Instrumentation, Campus Saint-Jerome, Marseille, France

We present the first results of induced oscillatory and rotational motion in superfluid helium-4, using a superconducting levitation system [1, 2] designed to investigate different regime flows in superfluid helium. From these experiments, some properties of the superfluid have been studied, such as viscosity, critical velocity and drag coefficient, demonstrating the system's viability as a versatile tool for exploring superfluidity and normal flows.

Current work includes the implementation of a detection system based on induction coils to track the levitating sphere when optical techniques are not feasible i.e. within a dilution refrigerator. This detection system will eventually lead to the conduction of similar experiments within superfluid helium-3.

[1] M. Arrayás et al., Sci Rep11, 20069 (2021).
[2] M. Arrayás et al., J Low Temp Phys (2023).

SA5.23 Visualization of the motion of small particles in turbulent superfluid ^{4}He at T < 1 K

Chris Goodwin[1], Ivan Skachko[1], Josh Hay[1], Matt Doyle[1], Wei Guo[2,3], Paul Walmsley[1], Andrei Golov[1]

[1]Department of Physics and Astronomy, University of Manchester, Manchester, UK
[2]Mechanical Engineering Department, Florida State University, Tallahassee, USA
[3]National High Magnetic Field Laboratory, Tallahassee, USA

In this experiment, fluorescent polymer spheres of radius 3 μm were impulsively injected into superfluid ^{4}He at temperatures down to 0.26 K, and their descent under both gravity and horizontal counterflow was filmed at 990 frames per second. At temperatures above 0.8 K, the particle trajectories are mainly smooth: they firstly reveal large-scale classical eddies caused by the injection process followed by a nearly straight descent at the terminal velocity later. However, below 0.8 K, when the viscous normal component is largely depleted, a more complex behaviour was observed: particles often move in a zig-zag manner, and their velocity PDF becomes wider and bi-modal. The obtained statistics will be shown along with the details of the experimental apparatus and particle-tracking algorithm.

SA5.24 Modelling turbulent flow of superfluid ^{4}He past a rough solid wall in the T = 0 limit

Matt Doyle[1], Andrew Baggaley[2], Paul Walmsley[1], Andrei Golov[1]

[1]Department of Physics and Astronomy, University of Manchester, Manchester, UK
[2]Joint Quantum Centre (JQC) Durham-Newcastle, School of Mathematics, Statistics and Physics, Newcastle University, Newcastle upon Tyne, UK

Using the vortex filament method, we modelled vortex tangles sustained in a flow of pure superfluid ^{4}He at T = 0 through a channel of width D = 1 mm at a given mean flow velocity V. The flat walls are assumed to be microscopically rough such that vortex ends, terminated at walls, are permanently pinned; the vortex liberation is purely through its self-reconnection with its image. There were periodic boundary conditions in the stream-wise and span-wise directions. The Bio-Savart integral was evaluated within the cut-off radius of D/2.

Sustained tangles were observed above the critical velocity $V_c \approx 0.20$ cm/s, which in non-dimensional form is $V_c D/\kappa \sim 20$. The coarse-grained velocity profile was steady and nearly parabolic, albeit with a non-zero slip velocity at solid boundaries whose value is close to that of V_c. The force-velocity relation was approximately linear, the resulting effective kinematic viscosity being $\nu' \sim 0.3\kappa - 0.1\kappa$ in the investigated range of V between 0.20 and 0.34 cm/s. The effective Reynolds number, $Re = (V - V_c)D/\nu'$, was hence between 0 and ~15, obviously insufficient to support quasi-classical turbulence in the coarse-grained velocity field. We thus had a polarized ultraquantum turbulence driven by injections of short-wavelength Kelvin waves upon frequent reconnections of vortex ends due to the relative motion of the vortex tangle and the rough wall.

SA5.25 **A universal profile of a beam of charged vortex rings in superfluid ^{4}He in the $T = 0$ limit**

Sio Lon Chan, Paul Walmsley, Andrei Golov

Department of Physics and Astronomy, University of Manchester, Manchester, UK

We investigated the longitudinal profile of the density $n(x)$ of charged vortex rings (CVR) in ^{4}He at $T < 0.5$ K, instantaneously released as a compact cloud of CVRs of small initial radius $R \sim 1$ μm and then propelled by an electric field $E \sim 15 – 50$ V/cm over the distance 3.0 cm to the collector, approaching which CVRs grow to $R \sim 100$ μm. The profile $n(x) = j/(eV)$ is determined from the time-dependent density of collector current *j(t)* due to CVRs, where $V \sim \kappa/R$ is the mean velocity of the of CVRs arriving at collector at $t = \tau$, and $x = (t - \tau)V$. The profile $n(x)$ is bell-shaped with exponential leading and trailing edges, whose decay lengths become equal in sufficiently strong fields $E \sim 50$ V/cm – making $n(x)$ look like $n \propto cosh^2(x/a)$. Interestingly, the same shape was also observed in experiments with ballistic beams of unidirectional CVRs in zero field [1] and also with charged vortex tangles propagating in electric field [2]. The theory in [1] relates the shape of $n(x)$ to the gas-like behaviour of interacting CVRs and the specifics of the relation $V \sim \kappa/R$. The width a obtained in our experiments is of a similar order of magnitude to that observed in [1] yet several times larger. We provisionally attribute this discrepancy to the difference between ring-ring interactions in ballistic and forced beams.

[1] G. Gamota, A. Hasegawa, C. M. Varma, Phys. Rev. Lett. **26**, 960 (1971).
[2] P. A. Tompsett, PhD thesis, University of Manchester, 2012.

4.7 Invited Oral Presentations: Monday 14th August

MO1.1 **The AB transition in superfluid ^{3}He and cosmological phase transitions**

Mark Hindmarsh[1,2,5], Stephan Huber[1], Asier Lopez-Eiguren[3,4], Kari Rummukainen[2,5], Kuang Zhang[1,5]

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First order phase transitions in the very early universe are a prediction of many extensions of the Standard Model of particle physics and could provide the departure from equilibrium needed for a dynamical explanation of the baryon asymmetry of the Universe. They could also produce gravitational waves of a frequency observable by future space-based detectors such as the Laser Interferometer Space Antenna (LISA). All calculations of the gravitational wave power spectrum rely on a relativistic version of the classical nucleation theory of Cahn-Hilliard and Langer, due to Coleman and Linde. The high purity and precise control of pressure and temperature achievable in the laboratory make the superfluid ^{3}He AB transition ideal for testing the theory. Yet when the A phase of superfluid ^{3}He is supercooled, the B phase appears far faster than classical nucleation theory would predict. If the appearance of B phase is due to a new rapid intrinsic mechanism, gravitational wave production could be rendered negligible.
Here we discuss studies of the AB phase transition dynamics in ^{3}He, both experimental and theoretical, and show how the computational technology for cosmological phase transition can be used to simulate the dynamics of the AB transition, and to support the experimental investigation of the AB transition in the QUEST-DMC collaboration.

MO1.2 **Superfluid bathtub vortex: a potential simulator of a quantum black hole**

Patrik Švančara[1], Pietro Smaniotto[1], Leonardo Solidoro[1], Sam Patrick[2], Carlo F. Barenghi[3], Ruth Gregory[2], Silke Weinfurtner[1]

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[2]Department of Physics, King's College London, London, UK, [3]School of Mathematics, Statistics and Physics, Newcastle University, Newcastle-upon-Tyne, UK

Analogue models of gravity have become useful tools for studying the behaviour of fields in curved spacetimes. A particular example is a draining (bathtub) vortex. It can be shown that its velocity field mimics the spacetime of a rotating black hole if the probing field is represented by gravity waves that propagate on the fluid interface. The relevance of this system as a black hole simulator has been recently underlined by direct observations of superradiance and quasinormal modes in a draining water tank [1,2]. We realise a similar system, i.e., a stationary draining vortex, in He II. Ripples propagating on the superfluid interface are detected by the synthetic Schlieren technique and decomposed into their spectral components. We find that the underlying velocity field imprints into these spectra and can be experimentally retrieved. The obtained velocity profiles indicate the presence of a polarised vortex tangle near the hollow vortex core, carrying 10^3 – 10^5 circulation quanta. These first results pave the way towards a regime where the quantization of circulation becomes important [3], therefore simulating the behaviour of a quantum black hole. This research is a part of the Quantum Simulators for Fundamental Physics consortium.

[1] Torres et al., Rotational superradiant scattering in a vortex flow, Nat. Phys. 13, 833:836 (2017)
[2] Torres et al., Quasinormal Mode Oscillations in an Analogue Black Hole Experiment, Phys. Rev. Lett. 125, 011301 (2020)
[3] Geelmuyden et al., Sound-ring radiation of expanding vortex clusters, Phys. Rev. Research 4, 023099 (2022)

MO1.3 Searching for Axions and Nonlinear QED with high-Q Superconducting Resonators

Hikaru Ueki[1, 2], Mehdi Zarea[1, 2], James Sauls[1, 2]

[1]Department of Physics & Astronomy, Louisiana State University, Baton Rouge, USA
[2]Hearne Institute of Theoretical Physics, Louisiana State University, Baton Rouge, USA

Superconducting Radio-Frequency (SRF) cavities have been developed with quality factors approaching, $Q{\sim}10^{12}$, for applications as detectors for rare events such as light by light scattering in nonlinear quantum electrodynamics (QED), weak coupling of dark matter (DM) candidates to microwave photons, or the detection of high-frequency gravitational waves. Bogorad et al. proposed a detecting evidence of axions, as well as photon-photon scattering in QED, by measuring signal photons at 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 [1]. Essential to the operation of the SRF cavity as a detector is the confinement of the EM field in the cavity by Meissner currents at three resonant frequencies of the cavity. We show how the intrinsic nonlinearity of the Meissner screening current as a function of EM field amplitudes [2] can be used to isolate the signal photons for the hypothesized Axion field as well as provide a novel test of the prediction of Euler and Heisenberg of photon-photon scattering mediated by virtual electron-positron pairs [3].

* The research is supported by the U.S. Department of Energy, Office of Science, National Quantum Information Science Research Centers, Superconducting Quantum Materials and Systems Center (SQMS) under contract number DE-AC02-07CH11359.

[1] Z. Bogorad et al., Phys. Rev. Lett. **123**, 021801 (2019).
[2] J. A. Sauls, Prog. Theor. Exp. Phys. **2022**, 033I03 (2022).
[3] W. Heisenberg and H. Euler, Z. Phys. **98**, 714 (1936).

MO1.4 Landau level spectroscopy and edge magnetoplasmons on electrons on Helium

Alexei Chepelianskii, Miguel Monteverde, Yan Sun, Vadim Derkach

Laboratoire de Physique des solides, CNRS, Orsay, France

Electrons on helium display rich out of equilibrium physics under microwave irradiation with the formation of zero resistance and incompressible states. We will introduce some results on the spectroscopy of Landau levels under tilted magnetic fields and show how these methods can be applied outside equilibrium to investigate the effect of nonlinear edge magnetoplasmon excitation.

MO2.1 **Nonlinear waves and solitons in superfluid helium films**

Christopher Baker[1], Walter Wasserman[1], Raymond Harrison[1], Glen Harris[1], Matthew Reeves[1], Seunghwi Kim[2], Andrea Alù[2], Warwick Bowen[1]

[1]ARC Centre of Excellence for Engineered Quantum Systems, The University of Queensland, Brisbane, Australia
[2]Photonics Initiative, Advanced Science Research Center, City University of New York, New York, USA

The observation of nonlinear wave dynamics and solitons in superfluid helium third sound has been a long sought-after objective [1]. In this talk, I will present new experimental results addressing this goal. Our approach employs a photonic crystal cavity fabricated at the end of a silicon photonic waveguide. This creates an optically-addressable quasi-one-dimensional wave tank containing a few femtoliters of superfluid helium. The superfluid film's minute thickness (~6 nm, roughly 20 monolayers) compared to the wave tank's dimension allows us to investigate hydrodynamic flows in extreme regimes (wavelength over thickness $\lambda/h > 10^4$).

Our approach incorporates both high-precision optomechanical readout techniques and strong actuation through the superfluid fountain pressure force [2], enabling the generation of large waves, whose amplitude is comparable to the film thickness. This leads to strong nonlinearities arising from the hydrodynamic flow itself, as well as from the nonlinear van der Waals restoring force. This novel platform enables us to generate and measure a rich variety of nonlinear superfluid phenomena, including backwards 'crashing' third sound waves, modulational instability/dissipative solitonic structures [2] and superfluid shock waves.

[1] F. M. Ellis and H. Luo, Third Sound: Where Are the Solitons?, J Low Temp Phys 89, 115 (1992).
[2] A. Sawadsky et al., Science Advances 9, eade3591 (2023); W. W. Wasserman et al., Opt. Express, 30, 30822 (2022); X. He et al., Nature Physics 16, 4 (2020); Y. P. Sachkou et al., Science 366, 1480 (2019).
[3] J. Zhang et al., Optomechanical Dissipative Solitons, Nature 600, 75 (2021).

MO2.2 **Optomechanics with magnetically levitated drops of liquid ^{3}He and ^{4}He**

Yogesh S. S. Patil

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Levitated liquid helium drops combine the features of low temperature, isolation, and superfluidity that play an important role in a range of disciplines [1] including optomechanics, wherein the drops' optical whispering gallery modes form an optical cavity, and their surface modes constitute the mechanics. The drops are expected to realize the unexplored regime of the single-photon optomechanical coupling rate $g_0 > \omega_{mech}$ (the mechanical frequency), approach the single-photon strong-coupling regime ($g_0 > \kappa_{opt}$, the optical cavity linewidth), and enable access to quantum nondemolition measurements of angular momentum for rotating ^{3}He drops [2].

Here, we report on recent [1] and ongoing experiments with millimeter-scale drops of pure ^{4}He and pure ^{3}He trapped by diamagnetic levitation in high vacuum. We measure the drops' temperature and evaporation rates, and characterize their surface waves, center-of-mass motion, and optical whispering gallery modes. These measurements are all in good agreement with theoretical predictions. We find that superfluid ^{4}He drops can be trapped indefinitely with a temperature of ~330 mK. Drops of ^{3}He are expected to reach lower temperatures, but their levitation at temperatures < 1 K is complicated by the dynamics of their nuclear spins.

[1] C. D. Brown, et al. Characterization of levitated superfluid Helium drops in high vacuum, PRL (in press)
[2] L. Childress, et al. Cavity optomechanics in a levitated Helium drop, PRA, 96, 063842 (2017)

MO2.3 Three-Tone Coherent Microwave Optomechanical Measurement of a Superfluid Helmholtz Resonator

Sebastian Spence[1], Emil Varga[2], Clinton A. Potts[3], John P. Davis[1]

[1]Department of Physics, University of Alberta, Edmonton, Canada
[2]Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic
[3]Kavli Institute of NanoScience, Delft University of Technology, Delft, Netherlands

Superfluid helium-4 is a promising mechanical element for cavity optomechanical and electromechanical experiments due to its large electronic bandgap, low dielectric loss, and ultra-low acoustic dissipation at millikelvin temperatures. We demonstrate measurement of the first microwave cavity-optomechanical integration of a superfluid Helmholtz device, further advancing development of our superfluid micromechanical resonators. The cavity-Helmholtz system brings recent kHz cavity-less electromechanical devices [1] into the GHz microwave regime, by coupling the pure superflow acoustic mode of the 'in-chip' microfluidic resonator to the electric field of the fundamental chip-cavity 3D microwave mode. This scheme demonstrates increased sensitivity over cavity-less readout methods, and avoids deleterious photothermal effects associated with optical probing. We measure the system using a new coherent measurement technique developed for measuring weak couplings deep into the sideband unresolved regime. Our technique is based on two-probe optomechanically induced transparency/amplification using amplitude modulation [2], but rather than measuring the two probe tones separately, we cancel them with one another to retain only signal coherent with the mechanical motion. We use this sensitive technique to measure a vacuum optomechanical coupling strength of $g0/2\pi = 25$ μHz, an improvement of three orders of magnitude over prior superfluid microwave experiments.

[1] E. Varga and J. P. Davis, New J. Phys. **23**, 113041 (2021).
[2] A. D. Kashkanova *et al*., J Opt. **19**, 034001 (2017).

MO2.4 Microwave optomechanics and cryogen-free nuclear demagnetization refrigeration

Andrew Fefferman[1], James Butterworth[2], Eddy Collin[1], Alexandre Delattre[1], Ilya Golokolenov[1], Tobias Kippenberg[3], Richard Pedurand[1], Matthias Raba[1], Sébastien Triqueneaux[1], Amir Youssefi[3]

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[2]Air Liquide Advanced Technologies, Sassenage, France
[3]Laboratory of Photonics and Quantum Measurement, EPFL, Lausanne, Switzerland

Cavity optomechanics is a powerful method for detecting the motion of nanomechanical resonators with quantum-limited sensitivity. The technique has several applications including mass sensing, mechanical quantum memory, transduction of signals at disparate frequencies, probing defects such as NV centers and low energy excitations in glass, dark matter searches, and investigating the conflict between quantum mechanics and general relativity.
Following pioneering demonstrations about a decade ago, optomechanical cooling of high-quality mechanical modes to the quantum ground state has now been achieved by several groups around the world. However, in these experiments the bath to which the mechanical mode is coupled remained relatively warm. But most applications of cavity optomechanics require a cold environment. For example, signatures of individual tunneling two level systems (TLS) coupled to a mechanical mode are only expected to appear if the TLS are near their ground state. Furthermore, the applications mentioned above benefit from coherence of the mechanical quantum state, which is reduced by the temperature of the environment and mechanical dissipation.

Thus there is a strong motivation to cool optomechanical devices well below 10 mK, and this was demonstrated in Grenoble [D. Cattiaux *et al.*, *Nature Comms.* (2021)]. More recently, we have greatly improved the noise level of our microkelvin optomechanical platforms, facilitating the search for individual TLS in glass. Furthermore, an ultra-low resistance superconducting heat switch was demonstrated as a crucial part of the continuous nuclear demagnetization refrigerator under development. Finally, microwave optomechanical measurements have been implemented on a dry nuclear demagnetization refrigerator.

MO3.1 Magnetic Susceptibility of Andreev Bound States in Superfluid 3He-B in Anisotropic Aerogel

John Scott, Man Nguyen, Daehan Park, William Halperin

Department of Physics and Astronomy, Northwestern University, Evanston, United States of America

Nuclear magnetic resonance measurements of the magnetic susceptibility of superfluid ^{3}He imbibed in a stretched aerogel reveal anomalous behavior at low temperatures. Although the frequency shift clearly identifies a low-temperature phase as the B phase, the magnetic susceptibility does not display the expected decrease associated with the formation of the opposite-spin Cooper pairs. Recent simulations of anisotropic aerogel have revealed plane-like structures in stretched aerogel. This susceptibility anomaly appears to be the predicted high-field behavior corresponding to the Ising-like magnetic character of surface Andreev bound states within planar confinement.

MO3.2 Oscillations of nematic aerogel in a superfluid medium

Evgeny Surovtsev

Department of Physical Problems, Kapitza Institute, Moscow, Russia

Experiments on vibrating wire with attached nematic aerogel in the superfluid ^{3}He provides information about superfluid properties of new phases appearing in the system in the presence of anisotropic aerogel. There are two oscillating modes observed in such a system: the first one is the mechanical resonance of the system observed in the whole range of temperatures and the second one is the analog of second sound of the superfluid system inside of aerogel which indicates the superfluid transition. The temperature dependence of frequencies of the above oscillating modes are sensitive to the value of superfluid density of ^{3}He inside of aerogel and can be used for extracting this important superfluid property of the system from the experimental data. Despite the fact that the origin of the observed modes can be easily guessed, the calculated superfluid density and its temperature dependence followed from two-fluid hydrodynamic equations incorporating the effect of impurities (Khalatnikov theory) does not correspond to that of pure ^{3}He. We believe that the given inconsistency is the consequence of several features of the considered system: anisotropy of nematic aerogel (axial symmetry) and a great difference between the velocity of first sound of ^{3}He and the sound velocities of nematic aerogel. In this talk we show that the solution of two-fluid hydrodynamic equations which takes into account the interaction between nematic aerogel and ^{3}He together with special boundary conditions imposed on the system yields the correct temperature dependencies of frequencies of two oscillating modes observed in the experiments.

MO3.3 Superfluid ^{3}He in Planar and Nematic Aerogels

Man Nguyen, Joshua Simon, John Scott, Andrew Zimmerman, Yun-Chieh Tsai, William Halperin

Physics and Astronomy, Northwestern University, Evanston, USA

The recent program of introducing aerogel impurities into superfluid ^{3}He has engineered many new phenomena and phases. These new condensed states are heavily reliant on the exact structure of anisotropic aerogel. Existing literature has largely focused on the simulation of isotropic aerogels. Here we present a framework that goes well beyond this by generating, analyzing, and classifying aerogels that exhibit large scale structure not found in isotropic aerogels. We have created anisotropic aerogels through a diffusion process that biases the diffusion along a single axis, generating two types of globally anisotropic aerogels which we call "planar" and "nematic". The characterization of the anisotropy employs a range of metrics. Our classification system enables us for the first time to provide a clear mechanism for the recently discovered "orbital-flop" transition, an orbital analog of the spin-flop transition [1]. Remarkably, this transition is shown to be independent of order parameter symmetry and is instead determined by the intricate aerogel structure.

[1] Zimmerman *et al.* Phys. Rev. Lett. **121**, 255303 (2018)

MO3.4 Neutron Imaging of an Operational Dilution Refrigerator

C.R. Lawson, A.T. Jones, W. Kockelmann, S. Horney, O. Kirichek

ISIS Neutron & Muon Source, Science & Technology Facilities Council, Harwell, UK

The dilution refrigerator is a low temperature workhorse, used worldwide to provide temperatures in the millikelvin range for devices ranging from quantum computers through to dark matter detectors. Since its inception more than 50 years ago, the mechanism by which refrigeration occurs has been well understood. However, until this point, the only visual representations of this process were illustrations in reference textbooks.

Likewise, neutron radiography has been in existence since last century, and is widely used by both science and industry to investigate material properties at facilities such as the ISIS Neutron & Muon Source. The current state-of-the-art imaging instrument at our facility, IMAT, provides neutron radiography, neutron tomography and energy-resolved neutron imaging.

In this work we combine dilution refrigeration and neutron imaging to showcase a new capability for the field of low temperature physics. Previous work has proved the potential for discerning ^{3}He from ^{4}He using neutrons, here we take the next step by imaging an entire dilution refrigerator during operation.

Our setup allows the capture of high-quality images and videos showing condensation of fridge mixture, ^{3}He/^{4}He phase separation, and 'single shot' diagnostic procedures. In addition, it is possible to demonstrate the changing concentration of 3He in the mixing chamber. We expect this work to have a wide-ranging impact for educators, technicians, and dilution refrigerator engineers.

MO4.1 The legacy of Henry Hall and Joe Vinen in the field of quantum fluids and beyond

Andrei Golov

Department of Physics and Astronomy, University of Manchester, Manchester, UK

I will review several episodes of the lasting impact left by Henry Hall and Joe Vinen:
(i) Their discovery, in the 1950s, that mutual friction between the superfluid and normal components is due to the scattering of excitations off vortex lines heralded a new era. The HVBK equations captured the coarse-grained hydrodynamics of polarized vortex bundles while the Vinen equation for vortex tangles in counterflow rested on the understanding of the dynamics of individual lines.
(ii) In 1965 in Manchester, Hall built a ^{3}He-^{4}He dilution refrigerator capable of achieving 65 mK – thus opening the now standard way to access mK temperatures, crucial to the whole field of QFS and far beyond.
(iii) Since mid-1970s, Henry led the UK efforts to investigate superfluid ^{3}He. Together with John Hook they were world's-first in many ways like the use of vibrating wire to probe excitations in ^{3}He, the measurements of the mutual friction in A and B phases, and the observations of textural transitions in ^{3}He-A where non-singular vortices and domain walls interact.
(iv) After his retirement in 1997, Vinen continued to be a passionate proponent of Quantum Turbulence (QT). His collaboration with Manchester, between 2004 and 2022, resulted in several landmark experiments on the dynamics of QT in the $T = 0$ limit.
(v) One of Joe's desires was to understand the microscopic dynamics of QT in the absence of thermal excitations. In Manchester, we built an apparatus to visualize vortices in ^{4}He at $T < 1$ K; preliminary results with solid particles as tracers will be reported.

MO4.2 Henry Hall and the Early Days of Superfluid ^{3}He at Manchester.

George Pickett

Department of Physics, Lancaster University, Lancaster, UK

I first met Henry when arrived in Lancaster after a post-doc in Helsinki. Those were interesting times. Henry and I were already working on the liquid heliums, and just after I arrived we started getting rumours that the superfluid transition in liquid ^{3}He had been observed in Cornell. This prompted a rush of low-temperature workers to reach the superfluid transition at around 2 mK which really needed nuclear cooling, then only in its infancy, backed by dilution refrigeration which was also a new idea. As I had been working with nuclear cooling in Helsinki and Henry was the co-inventor of the dilution refrigerator, we applied for a joint Manchester-Lancaster project to work in this new field, neither of us having quite the confidence to go it alone. However, Manchester as the "senior" partner, were given the go ahead and Lancaster was asked to wait until Manchester had got going. We were furious but in the interim Frossati came up with his vastly superior sintered silver dilution refrigerators and we decided to make our own machine which achieved 3 mK on its first full run and gave us a head start in the whole game. To get their machine going, I ended off working one day a week in Manchester and learned a lot from Henry, most usefully, the vibrating wire viscometer, which we developed to become the universal microkelvin tool. I will expand on those times in the talk.

MO4.3 Quantum turbulence: the legacy of W.F. Vinen

Carlo F. Barenghi

School of Mathematics, Statistics and Physics, Newcastle University, Newcastle upon Tyne, United Kingdom

The late W.F. "Joe" Vinen is remembered for influential experiments in many areas of low temperature physics. This talk is concerned with Vinen's pioneering experiments on heat currents in superfluid helium in the 1950s. My aim is to show that Vinen's experiments stood the test of time by identifying a phenomenon which has grown in significance and importance over the years: quantum turbulence.

Vinen's original interest in this problem was that the appearance of a disordered, turbulent tangle of quantised vortex lines limits the otherwise ideal heat-conducting properties of superfluid helium; heat transfer is indeed important in applications ranging from medicine to astronomy. In the 1990s it became apparent that quantum turbulence shares remarkable similarities with turbulence in ordinary (classical) fluids. Dissimilarities also appeared, stimulating interesting questions about the classical limit of out-of-equilibrium systems constrained by quantum mechanics. The experimental realization of Bose-Einstein condensation in cold atomic gases also led to studies of both two dimensional and three-dimensional quantum turbulence in settings unlike traditional helium 3 and helium 4; potential astrophysical applications (neutron stars and cold dark matter) have also been considered. The main types of quantum turbulence regimes which have been discovered will be discussed in this talk, together with the natural questions which arise from the comparison with classical turbulence.

MO4.4 Collective dynamics of ions and vortices in He II in experiments of Joe Vinen

Ladislav Skrbek

Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

Pools of positive and negative ions – tiny snowballs and bubbles – trapped by electric field underneath the surface of superfluid ^{4}He (He II) serve as a playground of classical two - dimensional (2D) physics. We discuss various collective modes of response of these systems to ac drive and their interaction with surface waves – ripplons, leading to detection of 2D Coulomb crystals. Collective dynamics of line defects in He II – quantized vortices – represent the essential ingredient of quantum turbulence. Since its discovery in pioneering Vinen's experiments on thermal counterflow of He II, quantum turbulence became established as a fast developing research field and represents an intellectual challenge for many investigators. We discuss the long-standing puzzles on transition to quantum turbulence and its temporal decay set by these early experiments and recent progress in disentangling them.

MO4.5 Studies on Quantum Turbulence with Vinen

Makoto Tsubota

Department of Physics, Osaka Metropolitan University, Osaka, Japan

Joe Vinen (1930–2022) was a great scientist who made a significant contribution to the field of quantum hydrodynamics and turbulence. In my research career in the field of quantum turbulence, I have been strongly encouraged by Vinen. In this talk, I review the works motivated by him and the joint works with him. Showing the research history of quantum turbulence, I would discuss such topics as quantum turbulence at zero temperature, Kolmogorov spectrum of a vortex tangle without mutual friction, and fully coupled dynamics of quantized vortices and normal fluid. Among the joint works with him, I would discuss diffusion of a vortex tangle, Kelvin wave cascade, quantum turbulence created by an oscillating object, and coupled dynamics of tracer particles and quantized vortices. I would show some episodes related with these studies.

MO4.6 Rotating quantum wave turbulence and onset of the Kelvin wave cascade

J. T. Mäkinen[1]

[1]Department of Applied Physics, Aalto University, Espoo, Finland
[2]Department of Physics, Lancaster University, Lancaster, UK
[3]Department of Physics, Royal Holloway, University of London, Egham, UK
[4]Finnish Meteorological Institute, Helsinki, Finland
[5]Department of Chemical Physics, Weizmann Institute of Science, Rehovot, Israel
[6]Department of Physics and Astronomy, The University of Manchester, Manchester, UK

Rotating turbulence in classical fluids can often be described as an ensemble of interacting inertial waves across a wide range of length scales. In superfluids vorticity is quantized, as first demonstrated experimentally by Vinen, and the nature of the transition between the quasiclassical dynamics at large scales and the corresponding dynamics at small scales remains an unresolved question. Also in contrast to classical fluids the spectrum of waves extends to microscopic scales as Kelvin waves on quantized vortices. In our experiments with rotating superfluid ^{3}He-B [1] we excite inertial waves at the largest scale by periodic modulation of the angular velocity as was pioneered by Hall in 1960. We observe dissipation-independent transfer of energy to smaller scales and the eventual onset of the Kelvin-wave cascade at the lowest temperatures. We find that our experimental observations are well described within the paradigm of wave-driven turbulence in rotating quantum fluids, where energy is pumped to the system through a boundary layer distinct from the classical Ekman layer. We uncover a new regime of turbulent motion in quantum fluids where the role of vortex reconnections can be neglected, simplifying the transition between the classical and the quantum regimes of turbulence.

[1] J. T. Mäkinen, S. Autti, P. J. Heikkinen, J. J. Hosio, R. Hänninen, V. S. L'vov, P. M. Walmsley, V. V. Zavjalov, and V. B. Eltsov, Rotating quantum wave turbulence, Nat. Phys. (2023), https://doi.org/10.1038/s41567-023-01966-z

4.8 Invited Oral Presentations: Tuesday 15th August

TU1.1 Development of the Continuous Sub-millikelvin Refrigerator

Ryo Toda, Shohei Takimoto, Satoshi Murakawa, **Hiroshi Fukuyama**

Cryogenic Research Center, The University of Tokyo, Tokyo, Japan

We have successfully constructed and tested a continuous sub-millikelvin (sub-mK) refrigerator consisting of two $PrNi_5$ nuclear demagnetization stages (NSs) and two zinc superconducting heat switches, which are connected in series and alternately. It was shown that the sub-mK refrigerator can keep the temperature at 0.72±0.01 mK continuously under a residual heat leak of 4−5 nW, and at any higher temperatures below 10 mK with higher cooling powers. This is the first experimental realization of the initial proposal of this new type of refrigerator [1] after the subsequent technical developments [2−4].
One of the NSs was repeatedly precooled down to 15−17 mK in a maximum field of 1.3 T with a ^{3}He-^{4}He dilution refrigerator, demagnetized, and remagnetized after pumping an entropy accumulated in the other NS, which was keeping the sample at any desired temperature under the residual heat leak and heat generation by measurement. One operation cycle took about 4 hours. The temperatures of the NSs were measured by platinum-wire pulsed NMR thermometers.
Due to its compactness (156W×84D×240H except the thermometers) and full automatic operation, this refrigerator will be useful for a wide range of applications to basic research and quantum technology. Improvements of the performance and software are now underway.

[1] R. Toda et al., J. Phys.: Conf. Ser. **969**, 012093 (2018).
[2] S. Takimoto et al., J. Low Temp. Phys. **201**, 179 (2020).
[3] S. Takimoto et al., J. Low Temp. Phys. **208**, 492 (2022).
[4] R. Toda et al., arXiv:2209.08260v1.

TU1.2 High performance rapid turn-around cryogen-free microkelvin platform: unlocking the sub-1mK temperature range for quantum materials research.

Jan Nyeki[1], Marijn Lucas[1,3], Petra Knappova[1], Lev Levitin[1], Andrew Casey[1], John Saunders[1], Harriet van der Vliet[2], Anthony Matthews[2]

[1]Department of Physics, Royal Holloway, University of London, Egham, United Kingdom
[2]Oxford Instruments NanoScience, Oxford Instruments, Abbingdon, United Kingdom
[3]Microsoft Quantum Delft, University of Delft, Delft, Netherlands

Improved accessibility to the microkelvin temperature regime is important for future research in quantum materials; quantum information science; applications of quantum sensors. Here we report the design and performance of a microkelvin platform based on a nuclear demagnetization stage, engineered, and optimized for operation on a standard cryogen-free dilution refrigerator [1]. $PrNi_5$ is used as the dominant refrigerant. The platform has a large area for mounting experiments in an ultralow temperature, low electromagnetic noise environment.
We demonstrate cooling to 395 μK. We have established a mode of operation, with a duty cycle in which we remain below 1mK for 95% of the time.
The platform has already provided an efficient cryogen-free microkelvin environment for the exploration of frontier science and technology on a range of systems. We highlight several collaborative experiments enabled by the European Microkelvin Platform.
The research leading to these results has received funding from the European Union’s Horizon 2020 Research and Innovation Programme, under Grant Agreement no. 824109.

[1] J Nyéki et al., Phys. Rev. Applied **18** L041022 (2022)

TU1.3 On-chip magnetic cooling of nanoelectronic devices

Jonathan Prance

Physics, Lancaster University, Lancaster, UK

Recent experiments have shown that the well-established technique of demagnetisation refrigeration can be miniaturised and integrated with small electronic devices to reach local electron temperatures below 1 mK [1-5]. Alongside the exciting possibility of studying electronic systems and materials in a new regime, the ability to cool devices far below 10 mK could have practical benefits for quantum technologies, metrological standards and sensors.

So far, on-chip magnetic cooling has been applied to a small range of devices, predominantly Coulomb blockade thermometers. For the technique to become more widely applicable, work is needed to better understand and manage the flow of heat between different materials and thermal subsystems in micro- and nano-scale structures. Looking at the problem another way, the magnetic refrigerant is an additional tool for controlling on-chip heat flow, which can facilitate better measurements of thermal properties like electron-phonon coupling and boundary resistances. This talk will review the current state-of-the-art in on-chip magnetic cooling and discuss recent progress towards making the technique more applicable in the future.

[1] Bradley et al., Scientific Reports 7, 45566 (2017)
[2] Sarsby et al., Nature Communications 11, 1492 (2020)
[3] Jones et al., Journal of Low Temperature Physics 201, 772 (2020)
[4] Samani et al., Phys. Rev. Research 4, 033225 (2022)
[5] Autti et al., arXiv:2209.07099 (2022)

TU2.1 Acoustic Casimir effect and fate of thermodynamics in mesoscopic matters.

Igor Todoshchenko, Alexander Savin, Marco Will, Elena Sergeicheva, Pertti Hakonen

Low Temperature Laboratory, Aalto University, Espoo, Finland

Size effects become crucial for thermodynamics at low temperatures when wavelength of thermal phonons becomes larger than the sample. We have observed such pushing phonons away in helium adsorbed on the carbon nanotube. However, zero-point phonons remain, and we have demonstrated that the "vacuum" pressure depends greatly on the length, the so-called acoustic Casimir effect. With the increase of temperature, we have observed that thermal phonons enter first to longer samples while short samples remain in zero-point state. As pressure depends on the size, and energy becomes not additive anymore, usual thermodynamics fails to describe small matters. The size of the sample becomes 4^{th} independent variable in thermodynamic potentials, in addition to P, T, and N. The additional coordinate promise to enrich greatly the phase diagrams; for instance, quadruple points become formally possible.

TU2.2 Supertransport in the core of dislocations in solid Helium-4.

Anatoly Kuklov

Physics and Astronomy, CUNY, New York, USA

The unique properties of the superflow-through-solid effect [1] are discussed from the perspective of the observations of the superfluidity along the cores of dislocations with the Burgers vector along the main symmetry axis in the hcp solid Helium-4. It is argued that thermal fluctuations of the edge dislocation shape induce strong suppression of the superfluid density. This mechanism can explain the unusual temperature dependence of the superflow rate [2], which has no analogy in any other system. While the superfluidity along the screw dislocation core is consistent with the Luttinger liquid paradigm, the superfluidity along the edge dislocation core demonstrates an essentially non-Luttinger behavior. Its main distinction comes from the parabolic spectrum of the excitations leading to the off-diagonal long range order in 1D at $T = 0$ [3]. It is shown that this feature is closely linked to the unusual nature of instantons causing the phase slip effects, and this can explain the experimentally observed IV characteristic [4].

[1] M. W. Ray and R. B. Hallock, Phys. Rev. Lett. 100, 235301 (2008); Phys. Rev. B 79, 224302 (2009); M. W. Ray and R. B. Hallock, Phys. Rev. B 81, 214523 (2010); J. Shin, D. Y. Kim, A. Haziot, and M. H. W. Chan, Phys. Rev. Lett. 118, 235301 (2017); J. Shin and M. H. W. Chan, Phys. Rev. B 99, 140502(R) (2019).
[2] Anatoly Kuklov, Lode Pollet, Nikolay Prokof'ev, Boris Svistunov, PRL, 128, 255301(2022).
[3] L. Liu and A. B. Kuklov, Phys. Rev. B 97, 104510 (2018).
[4] Leo Radzihovsky, Anatoly Kuklov, Nikolay Prokof'ev, Boris Svistunov, ArXiv: 2304.03309.

TU2.3 Influence of ortho-H_2 molecules on accumulation and spatial diffusion of H atoms in solid H_2 films.

Vladimir Khmelenko[1], Sergei Sheludiakov[2], Cameron Wetzel[1], David Lee[1], Jarno Jarvinen[3], Janne Ahokas[3], Sergey Vasiliev[3]

[1]Department of Physics and Astronomy, Texas A&M University, College Station, USA
[2]Department of Physics and Astronomy, University of Notre Dame, Notre Dame, USA
[3]Department of Physics and Astronomy, University of Turku, Turku, Finland

We report on electron spin resonance studies of H atoms stabilized in solid H_2 films at temperature 0.7 K and in a magnetic field of 4.6 T. We produced H atoms by bombarding H_2 films with 100 eV electrons produced during a radiofrequency discharge generated in the sample cell. We observed one order of magnitude faster H atom accumulation in the films made of H_2 gas with a small initial ortho-H_2 concentrations (0.2–3%) as compared with those made from the gas with a higher initial ortho-H_2 admixture [1]. We also investigated the influence of ortho-H_2 molecules on spatial diffusion of H atoms in solid H_2 films. The rate of spatial diffusion of H atoms in H_2 films with small initial ortho-H_2 concentrations was slower in comparison with that in the H_2 films with larger ortho-H_2 concentrations (5%-75%) [2]. We discuss possible explanations of these observations.

[1] S. Sheludiakov, C. K. Wetzel, D. M. Lee, V. V. Khmelenko, J. Järvinen, J. Ahokas, and S. Vasiliev, *Phys. Rev.* B **107**, 134110 (2023)
[2] S. Sheludiakov, D. M. Lee, V. V. Khmelenko, Yu. A. Dmitriev, J. Järvinen, J. Ahokas, and S. Vasiliev, *Phys. Rev.* B **105**, 144102 (2022)

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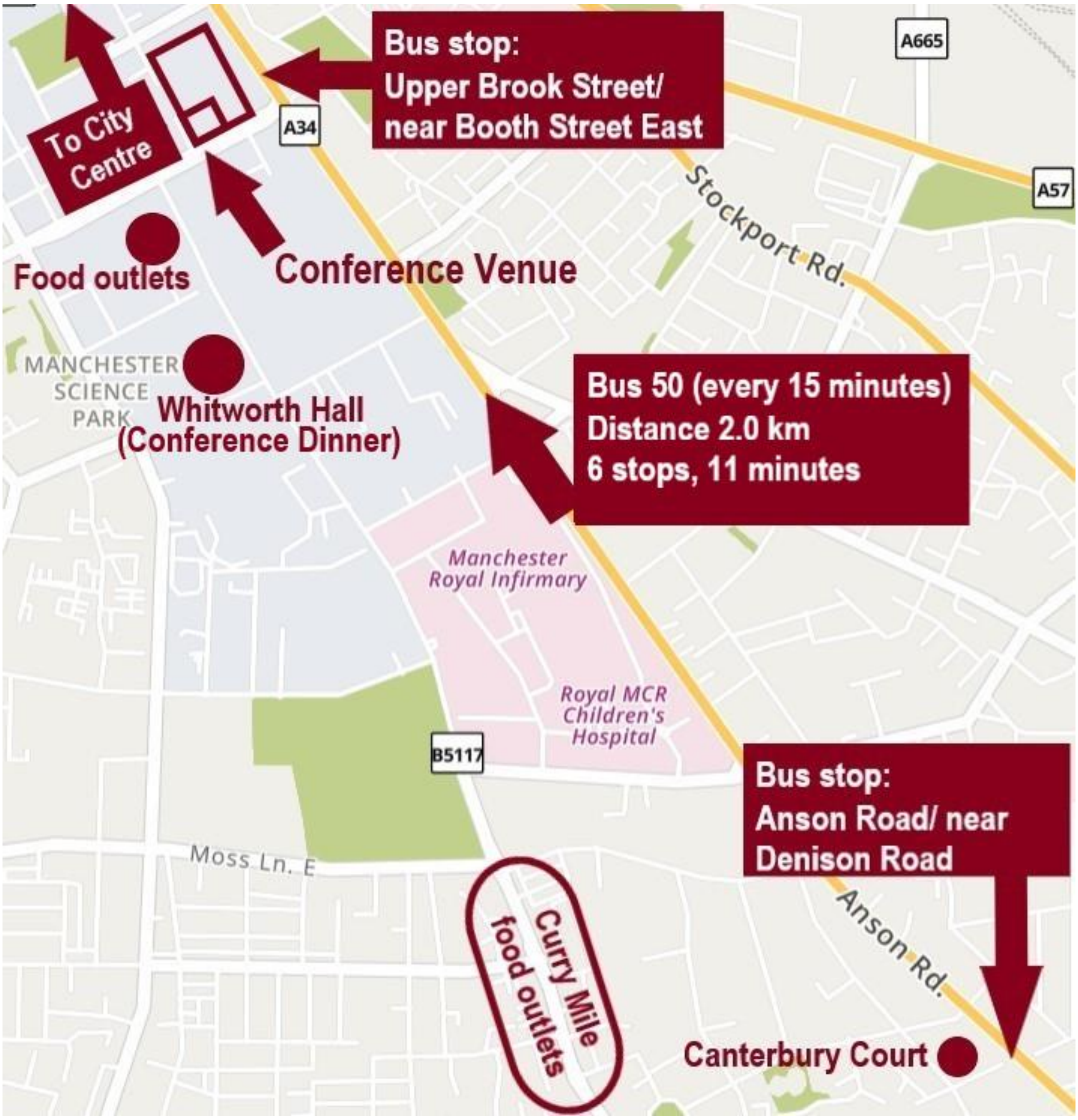

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Bus stop:
Upper Brook Street/
near Booth Street East
A34
A665
A57
Stockport Rd.
Food outlets
Conference Venue
MANCHESTER SCIENCE PARK
Whitworth Hall
(Conference Dinner)
Bus 50 (every 15 minutes)
Distance 2.0 km
6 stops, 11 minutes
Manchester Royal Infirmary
Royal MCR Children's Hospital
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Bus stop:
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Denison Road
Moss Ln. E
Curry Mile
food outlets
Anson Rd.
Canterbury Court