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SCALES



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EUROPEAN COOPERATION  
IN SCIENCE & TECHNOLOGY

**SCALES**  
**Training School**  
Turbulence  
and Vortex Dynamics  
**Book of Abstracts**

**2026**

# SCALES training school: Vortices and Turbulence

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# Program

	Monday, 6.7.	Tuesday, 7.7.	Wednesday, 8.7.	Thursday 9.7.	Friday 10.7.
09:00 -- 10:30	Registration 10:00	L2.1 <a href="#">Lanotte</a>	L3.1 <a href="#">Golov</a>	L4.1 <a href="#">Mäkinen</a>	L5.1 <a href="#">Krstulovic</a>
	Opening				
10:30 – 10:45	L1.1 <a href="#">Skrbek</a>	Coffee	Coffee	Coffee	Coffee
10:45 -- 12:15	12:00	L2.2 <a href="#">Gibert</a>	L3.2 <a href="#">La Mantia</a>	L4.2 <a href="#">Tsepelin</a>	L5.2 <a href="#">Del Pace</a>
12:15 - 13:30	Lunch	Lunch	Lunch	Lunch	Lunch
13:30 -- 15:00	L1.2 <a href="#">Barenghi</a>	L2.3 <a href="#">Weinfurtnr</a>	Transfer to Troja 14:30	Superfluid astro experiments	Open discussion; closing remarks
	15:00 – 15:30		Coffee	Labs	
15:30 -- 17:00	Coffee and posters	L2.4 <a href="#">Zmeev</a>			
				19:00 Conference dinner	

# Lectures

## Monday

### L1.1 Introduction to superfluidity and low temperature physics

**Ladislav Skrbek, Monday 10:30**

### L1.2 A primer on quantum turbulence

**Carlo Barenghi, Monday 13:30**

The plan of this lecture is to review the basics of three-dimensional turbulence in a quantum fluid. Starting from the definition of a quantum vortex, I shall proceed historically, and describe the early work on heat transfer in liquid helium, the studies that achieved contact with classical turbulence (revealing similarities and differences) and non-classical effects (such as the Kelvin wave cascade); finally I shall compare turbulence in helium and in classical fluid with turbulence in atomic Bose-Einstein condensates. In this progression, I shall also describe the theoretical models which are used at the macroscopic, mesoscopic and microscopic levels. The final part of the lecture will be concerned with applications of quantum turbulence to astrophysics.

## Tuesday

### L2.1 Turbulent cascades in classical flows: from 3D to 2D phenomenology

**Alessandra Lanotte, Tuesday 09:00**

I will give an introduction to turbulent cascades statistical theories in classical homogeneous and isotropic, incompressible flows. I will discuss separately the three-dimensional and the two dimensional phenomenologies, and then discuss how in the presence of anisotropy or spatial confinement, we may observe features of both.

### L2.2 A path toward rotating quantum turbulence revealed by direct visualization of quantum vortices in superfluid $^4\text{He}$

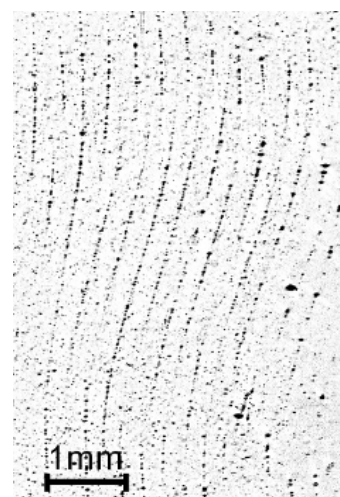
**Mathieu Gibert, Tuesday 10:45**

Discovered in 1937, the superfluid phase of liquid  $^4\text{He}$  (He II) remains a paradigm for exploring the rich and still only partially understood dynamics of quantum fluids. Among its most striking features are topological defects known as quantum vortices. In He II, applying heat flux in a closed end of a flow channel open at the other end generates counterflow turbulence, a unique form of turbulence characterized by a tangle of vortices where energy is transferred through vortex reconnections—with no classical equivalent.

Breaking the symmetry of this system by imposing rotation polarizes the vortex tangle, revealing a fundamentally new type of vortex dynamics. The initial state, a triangular vortex lattice governed by Feynman's rule [1], evolves into distinct hydrodynamical regimes when counterflow is imposed to the rotating superfluid sample. These were first investigated by Swanson et al. [2] using second-sound attenuation measurements, which identified two regimes separated by critical heat-flux thresholds, marked by an increase of vortex-line density.

In this course, we will revisit these seminal experiments and complement them with direct visualization of quantum vortices using the CryoLEM (Cryogenic Lagrangian Exploration Module). This state-of-the-art, temperature-controlled rotating cryostat enables the direct observation of vortices in He II by injecting micron-sized solid  $\text{H}_2$  or  $\text{D}_2$  tracers that attach to the vortex cores [1,3]. A heater inside the experimental volume allows us to quantitatively study counterflow regimes under rotation.

Through direct imaging and advanced image analysis, we demonstrate that the first regime identified by Swanson et al. [2] corresponds to a wave-like deformation of the vortex lattice (see Fig. 1). The presence of inertial waves is confirmed by frequency analysis and comparison with the theoretical dispersion relation for vortex waves in rotating He II [4]. Preliminary observations also suggest the presence of Kelvin waves, warranting further investigation.



Above the second critical threshold, we show that the system transitions to a turbulent state with strongly interacting vortices. We also explore how temperature and rotation influence the critical thresholds for this transition. For temperatures above 2 K, our measurements align qualitatively with the extrapolated results from [2], highlighting the complementarity of distinct approaches. Together, these experiments provide new pathways toward the exploration of rotating quantum turbulence.

- [1] C. Peretti et al., *Sci. Adv.* 9, eadh2899 (2023).
- [2] C.E. Swanson et al., *Phys. Rev. Lett.* 50(3), 190 (1983).
- [3] J. Vessaire et al., *Rev. Sci. Instrum.* 97, 025206 (2026).
- [4] K. L. Henderson, C. F. Barenghi, *Europhys. Lett.* 67(1), 56 (2004).

### L2.3 Superfluid helium 4 as a synthetic quantum system for non-equilibrium quantum field dynamics

**Silke Weinfurtner, Tuesday 13:30**

### L2.4 How to move a large object in superfluid helium at a constant speed and why bother

**Dmitry Zmeev, Tuesday 15:30**

Mechanical oscillators have probed superfluid helium since the field's origins—classic examples include Andronikashvili's torsional oscillator and Vinen's vibrating wire. Some modern experiments instead require a macroscopic object to move through the superfluid at a controlled, constant speed, which is technically challenging when energy dissipation must be strictly limited at (sub)millikelvin temperatures. I will present examples of measurements made possible by constant-speed motion [1] in both superfluid  $^4\text{He}$  [2] and superfluid  $^3\text{He}$  [3], and discuss practical solutions used to realize low-dissipation motion. I will also outline several experiments utilizing motion at a constant speed that could become feasible in the future.

- [1] Zmeev, D. E., *J. Low Temp. Phys.* 175, 480 (2014).
- [2] Zmeev, D. E. et al., *Phys. Rev. Lett.* 115, 155303 (2015).
- [3] Bradley, D. I. et al., *Nature Phys.* 12, 1017 (2016); Autti, S. et al., *Nature Comm.* 11, 4742 (2020); Autti, S. et al., *Nature Comm.* 14, 6819 (2023).

## Wednesday

### L3.1 Turbulence in superfluid $^4\text{He}$ in the $T=0$ limit: questions, achievements, and challenges

#### **Andrei Golov, Wednesday 09:00**

I will begin with a general outline of the specifics of quantum turbulence in  $^4\text{He}$  in the  $T = 0$  limit as different from the  $T > 1$  K regime. Existing paradigms and experimental evidence for them will be presented. Open questions and possible ways forward will be discussed. Experimental techniques, already available and speculative will be described.

Manchester experiments on the generation and characterization of the dynamics of various types of turbulence in  $^4\text{He}$  at  $T < 1$  K will be presented:

- generation of vortex tangles by ion jet, towed grid, rotational agitation, and impulsive spin-down
- measurements of the vortex line density by scattering charged vortex rings off them
- experiments with vortex arrays and tangles in rotation
- experiments with the motion of electrons along straight vortex lines and through a vortex tangle
- detection of a propagating turbulent front using vortex-trapped electrons and  $\text{He}_2^*$  excimers
- experiments with unidirectional vortex rings and their mutual scatterings
- visualization of the motion of micron-sized polymer particles through vortex tangles.

### L3.2 Turbulent flows of superfluid helium: a review of experimental findings

#### **Marco La Mantia, Wednesday 10:45**

The contribution of visualisation techniques to the phenomenological description of flows of superfluid helium-4 is summarised. The focus is on flows characterised by relatively high fluid velocity, occurring in the temperature range where viscous effects are not negligible. In particular, similarities and differences with related flows of Newtonian fluids are reported, including investigations on thermally generated vortex rings and on starting vortex flows at high Reynolds numbers. Special emphasis is given to the dependence of the observed features on the probed flow scales and on the presence of thermal gradients.

## Thursday

### L4.1 Helium-3 — Why and how to study it?

#### **Jere Mäkinen, Thursday 09:00**

During this lecture, I will give an introduction to helium-3, discuss its basic properties and connections to various fields of physics, cover the experimental techniques required to cool a sample of helium-3 down to sub-mK temperatures and for studying it, and go through a few examples from recent research development.

### L4.2 Visualizing Quantum Turbulence in Superfluid $^3\text{He-B}$ using Quasiparticles and Probing Single Vortices in $^4\text{He}$ using NEMS

#### **Viktor Tsepelin, Thursday 10:45**

We discuss experimental studies of quantum turbulence in superfluid  $^3\text{He-B}$ , the coldest currently accessible fermionic liquid. In addition to normal scattering, fermionic excitations can undergo Andreev reflection. At low temperatures, where the thermal excitations in the superfluid comprise ballistic quasiparticles, this process underpins the non-invasive imaging of topological structures such as quantum vortices or textures.

These structures can be produced via analogues of cosmological processes—for example, the Kibble mechanism—or by exceeding the Landau critical velocity to break the condensate. We have developed a 5x5 pixel quasiparticle camera operating at 150 microkelvin and demonstrate two-dimensional images of a quasiparticle beam and a tangle of quantized vortices (quantum turbulence) generated by a mechanical oscillator.

To fully understand this turbulence, the ability to study single vortices is essential. Nano-electromechanical systems (NEMS) are strong candidates for probing single-vortex dynamics, as they exhibit low power consumption and minute energy dissipation. Here, we utilize a  $\text{Si}_3\text{N}_4$  beam with aluminium metallization to investigate phenomena occurring in superfluid  $^4\text{He}$  at temperatures as low as 10 mK. Our results demonstrate that these nanoscale beams are ideally suited for the real-time detection of individual quantum vortices. We will present the interaction between our beam and a captured single vortex while offering insights into the dissipative processes that occur during this interaction.

## Friday

### L5.1 Probing vortex dynamics in ultracold atom superfluids

#### **Giulia Del Pace, Friday 09:00**

In this lecture I will review the main experimental technique to produce and probe a superfluid of ultracold atoms, highlighting the main characteristic of the bosonic and fermionic cases. I will then focus on the study of vortex dynamics on these platforms, reviewing the main experimental tools to inject and detect vortices together with some recent results achieved in the atomic superfluid community.

### L5.2 Quantum Vortex Dynamics and Turbulence through the Lens of the Gross–Pitaevskii Model

#### **Giorgio Krstulovic, Friday 10:45**

Superfluids are extraordinary fluids characterised by the complete absence of viscosity, with low-temperature helium (below 2.1 K) and atomic Bose–Einstein condensates as the most prominent examples. They are macroscopic manifestations of quantum mechanics and are routinely studied in the lab today. A defining feature of superfluids is their concentration of vorticity into extremely thin filaments—topological defects known as quantum vortices—where circulation is quantised. Despite their inviscid and quantum nature, superfluids share striking similarities with high-Reynolds-number classical flows and can be regarded as the skeleton of turbulent flows.

One of the most fundamental equations describing the dynamics of superfluids is the Gross–Pitaevskii model. Beneath its apparent mathematical simplicity lies a remarkably rich myriad of physical phenomena, including non-linear wave dynamics, quantum vortex nucleation, vortex dynamics and reconnection, and turbulence. Although this model is formally derived for weakly interacting Bose gases, its hydrodynamical description is rich enough to give an excellent qualitative description of superfluid helium.

In this lecture, I will first give an introduction to the Gross–Pitaevskii model and present its most fundamental solutions: density waves, quantum vortices and the connection to hydrodynamics. Then, I will follow a journey across scales, presenting theoretical and numerical results that range from the process of vortex reconnection to a fine comparison between classical and quantum turbulence, where the dynamics of intricate vortex tangles lead to very complex statistics. Throughout the lecture, I will highlight the differences and similarities between classical and quantum fluids, uncovering the universal phenomena they share. In the final part of the lecture, I will briefly illustrate how the Gross–Pitaevskii model can be extended to incorporate the dynamics of moving and reacting objects, and how it may be generalised to offer a more accurate description of superfluid helium.

# Posters

## **P1 Spontaneous Quantum Turbulence in a Newborn Bose-Einstein Condensate via the Kibble-Zurek Mechanism**

Seong-Ho Shinn

*University of Luxembourg*

The Kibble-Zurek mechanism (KZM) predicts the spontaneous formation of topological defects in a continuous phase transition driven at a finite rate. We propose the generation of spontaneous quantum turbulence (SQT) via the KZM during Bose-Einstein condensation induced by a thermal quench. Using numerical simulations of the stochastic projected Gross-Pitaevskii equation in two spatial dimensions, we describe the formation of a newborn Bose-Einstein condensate proliferated by quantum vortices. We establish the nonequilibrium universality of SQT through the Kibble-Zurek and Kolmogorov scaling of the incompressible kinetic energy.

## **P2 Imaging Quantum Turbulence in Superfluid $^4\text{He}$ in the $T \rightarrow 0$ Limit.**

C. O. Goodwin,<sup>1,2</sup> M. J. Doyle,<sup>1</sup> J. A. Hay,<sup>1</sup> I. Skachko,<sup>1</sup> W. Guo,<sup>3,4</sup> P. M. Walmsley,<sup>1</sup> and A. I. Golov<sup>1</sup>

<sup>1</sup>*Department of Physics and Astronomy, The University of Manchester, Manchester M13 9PL, UK*

<sup>2</sup>*School of Mathematical Sciences, The University of Nottingham, Nottingham NG7 2RD, UK*

<sup>3</sup>*Mechanical Engineering Department, Florida State University, Tallahassee, FL 32310, USA*

<sup>4</sup>*National High Magnetic Field Laboratory, Tallahassee, FL 32310, USA*

An injection system for polymer particles, with diameters ranging from 1 to 6  $\mu\text{m}$ , has been developed for visualizing flows in superfluid  $^4\text{He}$  at temperatures down to 0.14 K. Using an ultrasound transducer, bursts of particles were launched into a sample of superfluid and allowed to descend under gravity. The particles were imaged using their fluorescence in the presence of a sheet of laser light. We report on the statistical behaviour of particles during their descent, including descriptions of a mixture of smooth and erratic trajectories, indicative of the interactions with thermal excitations and quantized vortex lines. Temperature-dependent velocity distributions were measured and analysed, yielding Gaussian distributions with power law tails which, when sampled over increasing length scales, gave way to exponentials persisting into the zero temperature limit. We also report observations of long-lived suspensions of small particles at temperatures near 1 K, which appear to be associated with the trapping of large numbers of particles in a turbulent vortex tangle. A method was developed for identifying and quantifying the numbers of particles bound to vortex lines, allowing for a description of the temporal dynamics of their population by an analytical model.

## **P3 Rotating counterflow in Helium II: from waves to quantum turbulence**

Florian Lorin<sup>1</sup>, Corentin Bourjaillat<sup>1</sup>, Charles Peretti<sup>1,3</sup>, Patrik Švančara<sup>1</sup>, Pierre-Philippe Cortet<sup>2</sup>, Mathieu Gibert<sup>1</sup>

<sup>1</sup>*Univ. Grenoble Alpes, CNRS, Institut Néel, 38000 Grenoble, France*

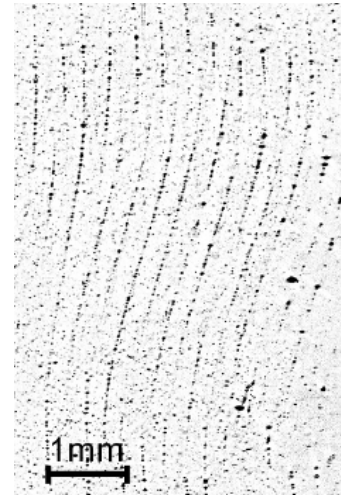
<sup>2</sup>*Univ. Paris-Saclay, CNRS, FAST, 91405 Orsay, France*

<sup>3</sup>*now at: National High Magnetic Field Laboratory, 1800 East Paul Dirac Drive, Tallahassee, Florida 32310, USA*

Discovered in 1937, Helium II is a key system for studying superfluid dynamics, which remains not fully understood. Superfluid phases have exotic properties, including the presence of topological defects known as quantum vortices. Counterflow quantum turbulence, which demonstrates energy transfer through vortex reconnections, has no classical counterpart.

Our experimental apparatus, the CryoLEM (Cryogenic Lagrangian Exploration Module), is a temperature-controlled, rotating cryostat designed for the direct visualization of vortices in He II through the injection of micron-size solid  $\text{H}_2$  or  $\text{D}_2$  tracers that stabilize on vortices [1,2]. A heater located in the experimental volume enables us to study counterflow regimes under rotation. The hydrodynamical regimes of rotating He II in counterflow were first studied in [3]. By imposing a

heat flux in the fluid, they observed an increase in vortex line density above a flux threshold, interpreted as a transition to turbulence. We demonstrate that the regime below this threshold is characterized by a wave-like deformation of the vortex lattice. The presence of inertial waves on the lattice becomes evident by analyzing its energy spectrum. The trace of Kelvin wave turbulent cascade, which is thought to be a key mechanism of dissipation in superfluids, is also discussed. Eventually, we observe that the regime above the threshold corresponds to a turbulent state of interacting vortices. To understand the role of the counterflow in this transition, we investigate the temperature dependence of this threshold. For  $T > 2$  K the extrapolated results from [3] align well with our findings.



[1] C. Peretti et al., *Sci. Adv.* 9, eadh2899 (2023).

[2] J. Vessaire, C. Peretti, F. Lorin et al., *Rev. Sci. Instr.* 97(2) (2026).

[3] C.E. Swanson et al., *Phys. Rev. Lett.* 50(3), 190 (1983).

#### **P4 Temperature Fluctuations and Heat Transport in Periodically Modulated Rayleigh - Bénard Convection**

Jiří Krempf

*Institute of Scientific Instruments, AV ČR, Brno*

Periodic temperature modulation in Rayleigh-Bénard convection leads to an enhancement of heat transport. We study the connection between this enhancement and local temperature fluctuations measured in the bulk. Experiments are performed in a cylindrical cell of aspect ratio  $\Gamma = 1$  using cryogenic helium gas as the working fluid, covering Rayleigh numbers  $Ra \in (10^8, 5 \cdot 10^{12})$  and a wide range of normalized modulation amplitudes  $A^*$  and frequencies  $f^*$ . We show that kurtosis of the temperature fluctuations correlates strongly with the enhancement of heat transport and propose an explanation based on the estimation of thermal dissipation rates. In contrast, the kurtosis shows no dependence on  $Ra$ . We further observe that modulated experiments exhibit significantly negative skewness, which might be attributed to enhanced cold plume emission from the modulated top plate. Motivated by recent results on atmospheric temperature variability, we examine the kurtosis – skewness relationship in our data and find no evidence of the quadratic scaling reported in atmospheric fields, and suggest this scaling may be a statistical artifact of finite dataset length.

#### **P5 Reproducible nucleation and control of stable quantum vortex rings in Bose-Einstein condensates**

Giorgia Iori

*Università degli Studi di Milano*

Understanding vortex dynamics in three-dimensional superfluid systems emerges as a key challenge. Driven by the ultracold quantum gases laboratory that has recently been established in Milan, our work aims at numerically investigating and controlling three-dimensional vortex ring formation and dynamics in trapped Bose-Einstein condensates.

We propose and numerically validate an experimentally feasible on-demand protocol for the nucleation and manipulation of stable quantum vortex rings in harmonically trapped cylindrical Bose-Einstein condensates. Sweeping a laser-sheet barrier through the condensate, we locally constrict the superflow and trigger vortex-ring formation. By tuning the barrier height and width, and by scanning the barrier velocity, we identify the onset of periodic vortex-ring generation above the critical velocity and achieve direct, deterministic control over the ring nucleation position, radius and hence propagation speed.

Once the ring has formed, we apply tailored local optical potentials to reshape the vortex ring and excite clean Kelvin waves on it, or deliberately induce its destabilisation.

Our results provide a foundation for systematic studies of three-dimensional vortices in atomic superfluids and open the door to tailored vortex dynamics and interactions, enabling controlled access to quantum turbulence.

### **P6 Wave Dynamics on Quantized Vortex Lattices in Rotating Superfluid Helium II**

Simone Scollo

*Observatoire de côte d'Azur*

Quantized vortices are the fundamental building blocks of superfluid turbulence, and understanding their collective dynamics is essential for describing energy transfer and dissipation in quantum fluids. In the context of superfluid helium II, we previously demonstrated through fully coupled two-fluid simulations using the FOUCAULT model that Kelvin waves propagating on vortex filaments induce a coherent response in the normal fluid, providing a potential route for their experimental detection through tracer-based visualization.

Building on this framework, the present work investigates the dynamics of rotating superfluid helium II subjected to an axial thermal counterflow. To model this configuration, we extended FOUCAULT by implementing boundary conditions for a rotating cylindrical container. The simulations reproduce a stable vortex lattice that, under increasing heat flux, develops collective wave excitations.

Current work focuses on characterizing this transient regime, in which coherent perturbations are expected to propagate along the vortex array. Preliminary numerical results exhibit behavior consistent with recent observations from the CryoLEM experiment conducted by the group of Mathieu Gibert. Comparison with these experiments aims to improve our understanding of the transition from an ordered vortex lattice to quantum turbulence in rotating helium II and to provide a numerical framework for interpreting the experimental observations.

### **P7 Tkachenko waves in a lattice of quantum vortices in superfluid helium**

Adele Di Stefano

*Università di Torino*

This work explores the dynamics of Tkachenko waves across different geometries and domain sizes. We study the system in two dimensions at absolute zero ( $T = 0$ ) using the point vortex model under two specific geometric constraints: a domain with periodic boundary conditions and a disk. By relaxing these systems to their ground states and introducing perturbations in the linear regime, we extract the whole wave dispersion relation from numerical simulations, finding good agreement with new exact theoretical predictions. Finally, to bridge these theoretical models with finite-temperature superfluids, we implement the Foucault method in a quasi-two-dimensional configuration to account for the coupling between the vortices and the normal fluid.

### **P8 Decay of Macrovortices in Superfluids: A Cavity-QED Perspective**

Leandro A. Machado,<sup>1,2</sup> Mônica A. Caracanhas,<sup>1</sup> Nikolaos P. Proukakis,<sup>2</sup> and Vanderlei S. Bagnato<sup>1</sup>

<sup>1</sup>*São Carlos Institute of Physics, University of São Paulo, São Carlos, Brazil*

<sup>2</sup>*School of Mathematics, Statistics and Physics, Newcastle University, Newcastle upon Tyne, United Kingdom*

Quantized vortices are among the most fundamental excitations of Bose-Einstein condensates and provide a direct manifestation of superfluidity. While singly quantized vortices are generally stable, vortices carrying multiple units of circulation are intrinsically unstable and tend to split into singly

quantized vortices. Understanding the mechanisms governing this instability is important both for the dynamics of quantum fluids and for the control of topological excitations in confined superfluids. Here we investigate the instability and decay dynamics of multiply quantized vortices in two-dimensional Bose-Einstein condensates by studying the coupling between localized excitations in the vortex core and collective sound-like excitations of the condensate. By analysing the spectrum of elementary excitations, we identify resonant interactions that trigger vortex splitting and determine the dominant decay channels. To capture the essential physics, we develop an effective theoretical description in which the vortex-core excitation behaves as a discrete mode coupled to a confined phononic environment. This establishes a direct analogy with cavity quantum electrodynamics, where the vortex core plays the role of an effective emitter and condensate phonons act as confined radiation modes. Within this picture, the instability is governed by spectral resonances, coupling strengths, and the density of available phonon states. We show that confinement and boundary conditions strongly modify the decay dynamics by discretizing the phonon spectrum, leading to regimes of enhanced or suppressed instability analogous to Purcell-enhanced or inhibited emission in optical cavities. Depending on the spectral structure, the dynamics can exhibit both coherent mode hybridization and effectively irreversible decay. Our results establish a connection between vortex dynamics in superfluids and concepts from quantum optics, opening new possibilities for engineering and controlling topological excitations in quantum fluids.

**P9 Pressure and Size Dependence of Roton Emission and Vortex Creation by Moving Objects in He II in  $T \rightarrow 0$  Limit: Generalized Nonlocal Gross-Pitaevskii Model**

N. P. Müller,<sup>1,2</sup> L. Skrbek,<sup>3</sup> Y. A. Sergeev,<sup>4</sup> and G. Krstulovic<sup>5</sup>

<sup>1</sup>*Laboratoire de Physique des Plasmas (LPP), CNRS, Observatoire de Paris, Sorbonne Université*

<sup>2</sup>*Université Paris-Saclay, École polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France*

<sup>3</sup>*Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, Prague, 121 16, Czech Republic*

<sup>4</sup>*School of Mathematics, Statistics and Physics, Newcastle University, Newcastle upon Tyne NE1 7RU, United Kingdom*

<sup>5</sup>*Université Côte d'Azur, CNRS, Institut de Physique de Nice (INPHYNI), 17 rue Julien Lauprêtre, 06200 Nice, France*

In the framework of generalized, nonlocal Gross-Pitaevskii (GP) model, we study numerically the pressure- and size-dependent mechanisms of roton emission and vortex nucleation by objects moving in superfluid  $^4\text{He}$ . As far as the authors are aware, this is the first attempt to analyze the pressure dependence of these mechanisms and the associated critical velocities within a single theoretical framework. For each of several pressures in the range from 0 to the solidification pressure of around 25 bar, we chose the parameters of the interatomic interaction potential such that the resulting excitation spectrum for the generalized, nonlocal GP equation approximates fairly accurately the pressure-dependent dispersion curve determined experimentally by Godfrin et al., *Phys. Rev. B* **103**, 104516 (2021). In the two-dimensional approximation, for circular obstacles (disks) moving in quiescent  $^4\text{He}$ , we calculated two critical velocities – one corresponding to the roton emission and the other to the nucleation of quantized vortices – as functions of pressure and the obstacle's size. We also comment briefly on three-dimensional simulations of the roton emission and vortex nucleation by moving spherical obstacles.

## **P10 Decaying superfluid turbulence near an anomalous non-thermal fixed point**

Saskia Lach,<sup>1</sup> Niklas Rasch<sup>1</sup> and Thomas Gasenzer<sup>1,2</sup>

<sup>1</sup>*Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg*

<sup>2</sup>*Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg*

We study decaying quantum turbulence in a two-dimensional dilute Bose gas. The system is closed, conserving both particle number and energy. During the nonequilibrium evolution, it approaches an anomalous non-thermal fixed point characterized by universal self-similar scaling and anomalously slow vortex coarsening, with the mean inter-defect distance growing as  $\ell_v \sim t^\beta$  and  $\beta \approx 1/5$ . In the same dynamical regime, the second moment of the velocity circulation exhibits Kraichnan-Kolmogorov scaling. We further analyze the probability distribution of the velocity circulation in the inertial range and propose a scaling hypothesis for its probability mass function. The probability of zero circulation obeys the power law  $P(\Gamma = 0) \propto r^{-4/3}$ , which remains robust even for small system sizes. These results establish a connection between decaying quantum turbulence in a closed superfluid and universal dynamics near a non-thermal fixed point. We further present preliminary results on the analysis of zero-vorticity and density isolines within the framework of Schramm-Loewner evolution, finding signatures of conformal invariance.