Recent results obtained with the Prague second-sound attenuation technique applied to thermally and mechanically driven channel flows

Simone Babuin

Prague

We present an overview of the current state of experimental quantum turbulence research in Prague using the second-sound attenuation technique. We consider different superfluid 4He flows through square channels, with and without grid obstacles. As regards to steady flows, we compare the following scenarios: mechanically driven parallel flow of superfluid and normal component; flow of the superfluid component alone; thermally activated anti-parallel flow of superfluid and normal component (counterflow). We show remarkable differences in the L(V,T) characteristics (where letters stand respectively for vortex line density, mean velocity and temperature), related to the relative motion of the two components (hence on mutual friction force) and their relative motion to the walls (hence flow profiles). We also show how different harmonics of the second-sound resonance can be used to investigate the spatial distribution of the vortex line density across the flow direction, providing a new experimental test-ground for recent simulations. We also comment on the concept of "effective viscosity" offering an alternative derivation of this quantity from steady-state turbulence measurements. As regards to decaying turbulence, we offer a comprehensive set of results on the decay of mechanically driven superflow -- with supporting new measurements of thermally driven counterflow. This, together with complementary evidence from visualization experiments, will hopefully provide an experimental input for a deeper understanding of long-standing issues in counterflow, such as for example the dynamical state of the normal component.

Coherent laminar and turbulent motion of toroidal vortex bundles in superfluid helium

Andrew Baggaley

Newcastle

Abstract:

We numerically model experiments in which large-scale vortex rings—bundles of quantised vortex loops—are created in superfluid helium by a piston-cylinder arrangement. We find that the evolution of these large-scale vortex structures involves the generalised leapfrogging of the constituent vortex rings. Despite three dimensional perturbations in the form of Kelvin waves and vortex reconnections, toroidal vortex bundles retain their coherence over a relatively large distance (compared to their size). We also show that the presence of a normal-fluid vortex ring together with the quantised vortices is essential to explain the coherence of these large-scale vortex structures at nonzero temperatures, as observed experimentally. Finally we argue that the interaction of superfluid and normal-fluid vortex bundles is relevant to recent investigations of superfluid turbulence.

Spectral properties of superfluid turbulence

Carlo F. Barenghi[1]

Lucy Sherwin-Robson[1], Andrew W. Baggaley[1], and Yuri A. Sergeev[2]

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and [2] School of Mechanical and Systems Engineering,
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Turbulence occurs in many forms. The simplest case to study is turbulence away from boundaries in large enough domains sustained by external forcing in a statistical steady state, or decaying in time. Most observations of superfluid turbulence consist in measuring the turbulent velocity field by a small probe or the vortex line density via second sound attenuation or temperature gradients. Experiments and numerical simulations are compared against the classical Kolmogorov scaling of the velocity spectrum, which describes the distribution of kinetic energy over the length scales.

The results which we present are based on numerical simulations of superfluid vortex tangles. We look for a physical explanation of the observed scaling in terms of the dynamics of the vortex filaments.

In the discussion, we shall consider questions which are relevant to experiments, such as: why are two different regimes observed ? how does the spectrum build up ? what is the relation between the vortex line density spectrum and the velocity spectrum ?

Self-truncation and scaling in Euler-Voigt-α and related fluid models

Giuseppe Di Molfetta, Giorgio Krstlulovic, **Marc Brachet (speaker)**

A generalization of the 3D Euler-Voigt-α model is obtained by introducing derivatives of arbitrary order β (instead of 2) in the Helmholtz operator. The β→∞ limit is shown to correspond to Galerkin truncation of the Euler equation. Direct numerical simulations (DNS) of the model are performed with resolutions up to 20483 and Taylor-Green initial data. DNS performed at large β demonstrate that this simple classical hydrodynamical model presents a self-truncation behavior, similar to that previously observed for the Gross-Pitaeveskii equation in Krstulovic and Brachet [Phys. Rev. Lett. 106, 115303 (2011)]. The self-truncation regime of the generalized model is shown to reproduce the behavior of the truncated Euler equation demonstrated in Cichowlas et al. [Phys. Rev. Lett. 95, 264502 (2005)]. The long-time growth of the self-truncation wavenumber kst appears to be self-similar.

Two related α-Voigt versions of the EDQNM model and the Leith model are introduced. These simplified theoretical models are shown to reasonably reproduce intermediate time DNS results. The values of the self-similar exponents of these models are found analytically.

Internal structure of vortices in superfluids and implications for quantum turbulence

Laurent Chevillard

Lyon

Dense Bose superfluids, as HeII, differ from dilute ones by the existence of a roton minimum in their excitation spectrum. It is known that this roton minimum is qualitatively responsible for density oscillations close to any singularity, such as vortex cores, or close to solid boundaries. We show that the period of these oscillations, and their exponential decrease with the distance to the singularity, are fully determined by the depth and the width of the roton minimum. We then study, based on a numerical simulation of the Gross-Pitaevskii equation with a non-local interaction term, the implication of these oscillations on the vortex reconnection process, and quantify the amount of energy transfered from vortices to the background flow.

Observation of turbulence of inertial and Kelvin waves in superfluid 3He-B

V.B. Eltsov, S. Autti, P.J. Heikkinen, V.S. L'vov, J.T. Mäkinen, V.V. Zavjalov

Low Temperature Laboratory, Department of Applied Physics, Aalto University, Finland

We have excited wave turbulence on an array of vortex line in rotating superfluid 3He-B by periodically modulating rotation velocity. We have studied decay of the turbulence after stopping the excitation using magnon BEC to measure density and polarization of vortex lines as a function of time. At temperatures below 0.2Tc the results demonstrate existence of inertial-wave turbulent energy cascade at length scales larger than the intervortex distance. At smaller scales we observe transition from the mutual-friction dominated damping of Kelvin waves at higher temperatures to the temperature- and friction-independent dissipation at lower temperatures. This transition occurs at a value of the mutual friction parameter \alpha which is consistent with theoretical predictions for the operation of the Kelvin-wave cascade. We interpret this observation as a possible experimental evidence for the cascade.

Statistical and dynamical tools to study superfluid turbulence

Davide Faranda

CEA Saclay

Abstract:

More and more experimental data-set are available for superfluid turbulence and they need to be used to validate or disprove the theoretical predictions. Although spectral analysis remains the prefered tool to explore the behavior of turbulent flows, I will present some alternative techniques for the study of velocity (and not only) time series in the physical space. The idea is to introduce statistical tools based on the use of Auto-Regressive Moving-Average models, or the Extreme Value Theory, and define distances from known physical theories (e.g. Kolmogorov 1941). These tools will be used to highlight difference between superfluid turbulence and normal turbulence.

Coupled normal fluid and superfluid profiles in turbulent helium II counterflows

Luca Galantucci* and Carlo F. Barenghi†
Joint Quantum Centre (JQC), School of Mathematics and Statistics, Newcastle University, Newcastle upon Tyne, NE1 7RU, United Kingdom

Abstract

We perform fully coupled two–dimensional numerical simulations of plane channel helium II turbulent counterflows with vortex–line density typical of experiments. Peculiar to this work is the modeling of the back reaction of the superfluid vortices on the normal fluid and the presence of solid boundaries. Despite the reduced dimensionality, our model reproduces the vortex density profiles recently computed in three–dimensional counterflow channel simulations [1, 2] (v. Fig. 1 (left)). We focus on the coarse–grained superfluid and normal fluid velocity profiles recovering the normal fluid tail–flattened profile recently observed employing a technique based on laser–induced fluorescence of metastable helium molecules [3] and predicting a parabolic profile for the superfluid (v. Fig. 1 (right)).

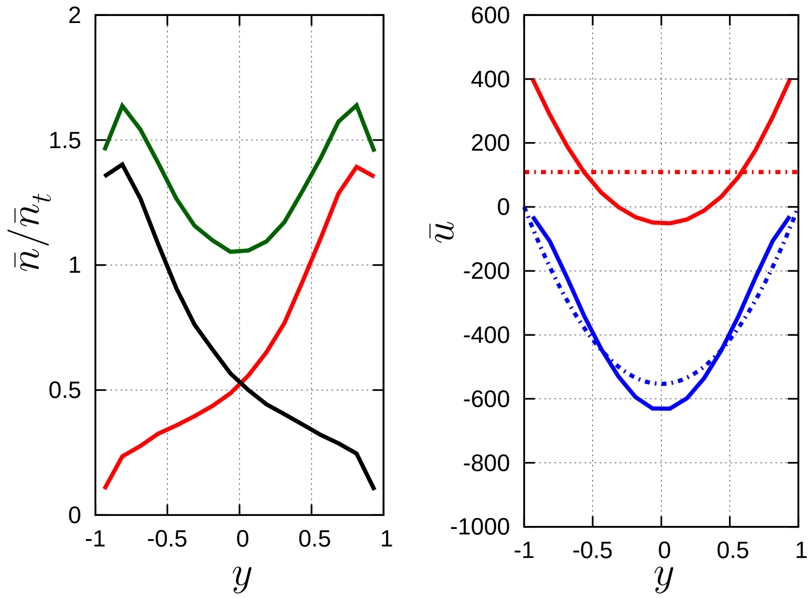

FIG. 1. (left): positive (red), negative (black) , total (green) vortex densities normalised by the average total vortex density; (right):Superfluid (red) and normal fluid (blue) laminar velocity profiles. Dot–dashed lines indicate the vortex–free profiles, solid lines refer to fully coupled calculations of vortex motion and normal fluid velocity field.

Afternoon session

In this context of helium II counterflow turbulence, the recent development of visualization techniques (especially Particle Tracking Velocimetry (PTV) [4, 5] and imaging of metastable helium molecules via laser–induced fluorescence [3]) has led to a deeper understanding of quantum turbulence. On numerical grounds, channel counterflow simulations have shown that when superfluid turbulence is driven by prescribed turbulent normal fluid flows the vortex density across the channel is more homogeneous with respect to simulations with laminar imposed normal flow [1, 6]. Would it be possible, therefore, to determine the vortex–density profile across the channel with the PTV technique by measuring the density of the vortex–trapped particles? Alternatively, would it be possible to determine the vortex–density profile measuring the attenuation of higher armonics of second sound waves? The achievement of this experimental objective could potentially allow to distinguish between laminar and turbulent normal fluid flows.

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The use of injected ions to probe and force vortex tangles and vortex arrays in superfluid helium

Andrei Golov
Manchester

I will discuss the use of injected ions to probe and to force vortex tangles and vortex arrays. Different techniques, suitable for generating turbulence at $T<1K$, will also be outlined.

Simultaneous study of the superfluid and the normal fluid in counterflowing superfluid helium-4

Wei Guo

Florida State

Abstract: We report a systematic study of thermal counterflow in superfluid helium-4 by combining flow visualization of the normal fluid and second-sound attenuation measurements of vortex line densities in the superfluid component. Visualization of the normal-fluid flow is achieved by tracking thin lines of metastable He_2 molecular tracers created by femtosecond-laser field-ionization in the helium, such tracking allowing us to observe both laminar velocity profiles and turbulent structure functions and energy spectra. We present experimental data showing how, with increasing heat flux, the flow of the normal fluid evolves from laminar Poiseuille to full, but non-classical, turbulence, and how these changes correlate with second-sound observations of the vortex line density in the superfluid component. Study of the decaying flow after the heat flux is removed has allowed us to confirm what has long been believed, that at long times there is quasi-classical coupled turbulence in the two fluids with a Kolmogorov spectrum, and it has allowed us also to trace how this coupled turbulence evolves from forms of non-classical flow in the steady state.

Approach and separation of quantum vortices with balanced cores

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Using two innovations, smooth, but distinctly different, scaling laws for the numerical reconnection of pairs of initially orthogonal and anti-parallel quantum vortices are obtained using the three-dimensional Gross-Pitaevskii equations, the simplest mean-field non-linear Schr ödinger equation for a quantum fluid. The first innovation suppresses temporal fluctuations by using an initial density profile that is slightly below the usual two-dimensional steady-state Padé approximate profiles. The second innovation is to find the trajectories of the quantum vortices from a pseudo-vorticity constructed on the three-dimensional grid from the gradients of the wave function. These trajectories then allow one to calculate the Frenet-Serret frames and the curvature of the vortex lines. For the anti-parallel case, the scaling laws just before and after reconnection obey the dimensional $\delta \sim |t_r - t|^{1/2}$ prediction with temporal symmetry about the reconnection time tr and physical space symmetry about x_r, the mid-point between the vortices, with extensions of the vortex lines formng the edges of an equilateral pyramid. For all of the orthogonal cases, before reconnection $\delta_{in} \sim (t-t_r)^{1/3}$ and after reconnection $\delta_{out} \sim (t - t_r)^{2/3}$, which are respectively slower and faster than the dimensional prediction. In these cases, the reconnection takes place in a plane defined by the directions of the curvature and vorticity.

Analytic Solution of the Approach of Quantum Vortices Towards Reconnection

Laurent Baué, Dmytro Khomenko, Victor L'vov & Itamar Procaccia
Department of Chemical Physics, Weizmann Institute of Science, Rehovot 76100, Israel

Liquid Helium at temperatures lower than two degree Kelvin becomes a superfluid with zero viscosity. Nevertheless, any initial flow conditions is seen experimentally to decay in time. Thus there must exist dissipative mechanisms besides viscosity that need to be understood. It is believed that reconnection of quantum vortices plays a key role in those mechanisms.

Experimental[1] and numerical studies[2] of the dynamics of vortex reconnection in quantum fluids showed that the distance d between the reconnecting vortices is close to a universal time dependence $d = D[\kappa(t_0 - t)]^\alpha$ with α fluctuating around 1/2 and $\kappa = h/m$ is the quantum of circulation. The theoretical calculation of the dimensionless coefficient D in this formula remained an open problem. In our talk we will discuss analytic solution of vortex reconnection dynamic and calculate the coefficient D.

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Dynamics of intense heat pulses interacting with vortices they generate in He-II. The Vinen's equation.

Luiza Kondaurova

Institute of Thermophysics, Novosibirsk, Russia

The interest to quantum turbulence is substantiated by the few moments. Firstly, motivation for research of quantized vortex filaments is connected with the fact that the theory of superfluid turbulence is important in many applications related to the quantum fluids. The development of some branches of science and technology, especially the application of superconductivity to create strong stationary magnetic fields dictated the need for the sustainable systems functioning at temperatures below 2 K. At these temperatures, the only real refrigerant is the superfluid helium. Secondly, the doctrine of quantum turbulence, as a part of the theory of superfluidity, is closely linked with other problems of the general theory of quantum liquids, such as the generation of vortices, the interaction between closely spaced vortex filaments, and hence, their reconnections, definition of the role of quantum vortices in phase transitions , etc. Besides the fact that the superfluid turbulence is of great importance in the above cases, the theory of stochastic vortex tangle in quantum liquids is of great interest and importance in terms of general physics, because there are similar systems of one-dimensional unordered the set of the one-dimensional singularities in many physical fields, such as a dislocation in solids, linear topological defects in the liquid crystals, polymer chains, etc.

In the study of the processes of heat transfer in applications and dynamics of nonlinear waves of second sound the equations of hydrodynamics of superfluid turbulence (*HST*) are used. The evolution equation of the density of the vortex filaments is included in the *HST* system. In his seminal works Vinen introduced a phenomenological model for the evolution of the vortex line density *L(t)* in a homogeneous vortex tangle. We have studied the dynamics of intense heat pulses at different temperatures when the nonlinearity coefficient of second sound takes a positive, negative and zero values. The dynamics of single and periodic pulses were investigated. It has been shown that the agreement with the experimental data is observed when changing the values of the coefficients in the equation Vinen.

Vinen himself in his work notes that this dynamic equation can have a different form. Schwartz from consideration of the kinetics of vortex loops received a similar form of the equation. When constructing equations HTS the dependence of value of L from the coordinates is introduced. In the work of D. Khomenko, L. Kondaurova, V. S. L'vov P. Mishra, A. Pomyalov, I. Procaccia "Dynamics of the density of quantized vortex lines in superfluid turbulence" (manuscript accepted for publication in a Rapid Communication in Physical Review B) the new form of the dynamic equation of the density of the vortex filaments is suggested. Today it remains an open question.

Today, there are well-established fact, namely, in the stationary case Vinen's equation yields the relation: $L^{1/2} = \gamma_V V_{ns}$. A comparison of experimental and theoretical values of the γ is an issue that requires careful analysis of particular experimental conditions including the dependence on the channel width, the roughness of the walls, the finite value of the temperature difference with respect to the mean temperature and problems with temperature stabilization. Additional uncertainty arises from the fact that the thermal counterflow turbulence in square channels of width smaller than 1 mm may exist in two turbulent regimes. The regime *TI* immediately follows the laminar state. The regime *TII* is found above some critical line density, usually at higher counterflow velocities. All these problems lead to a wide spread of experimental values of γ. These values of the coefficient $\gamma_V = \pi B \rho_n \chi_1 / \kappa \rho \chi_2$ with experimental values for *B* and χ_1, χ_2. are close to the experimental γ measured in superflow. The values of γ for pure superflow are significantly larger than those for counterflows in TI. Ignoring these differences in the experimental conditions, we obtained that i) the spread of numerical results obtained under uniform periodic conditions to uniform counterflow (velocity fluctuations in turbulent normal fluid is neglected) is smaller than that of the experimental data; ii) the numerical results lie within the spread of experimental values of γ and are in agreement with the experimental γ of A. Marakov et al. (PRB **91**, 094503 (2015)). Numerical results γ of A. W. Baggaley and S. Laurie (J. Low Temp. Phys. **178**, 35 (2014)) and of Satoshi Yui and Makoto Tsubota (PRB **91**, 184504 (2015)) to turbulent normal fluid in the presence of walls are close to the experimental γ measured in superflow.

More experimental work is needed to better measure the values of γ (so the *T1-T2* transition, the transition from laminar to turbulent state and the profiles of the physical quantities over the channel cross section depend on the channel geometry, temperature values), as well as receiving the evolution equation for density of the vortex filaments.

The work was financially supported by RFBR (Grants No. 13-08-00673 and No. 15-02-05366).

Some recent results on low temperature quantum turbulence

Giorgio Krstulovic

Nice Observatory

In this talk I will present some recent numerical results obtained using the Gross-Pitaevskii equation. I will present some different turbulent settings that will be compared with its classical counterpart of classical turbulence. Although these Gross-Pitaevskii results are formally valid only for weakly interacting Bose-Einstein condensates it is expected that the results will also apply to superfluid Helium.

Effectiveness of small-scale energy transfer mechanisms in zero temperature superfluid turbulence

Jason Laurie
Weizmann

We present new results on the effectiveness of potential small-scale energy transfer mechanisms in superfluid turbulence. In a series of numerical simulations, we identify to what extent the structure (polarization) of the large-scale flow has upon the generation of vortex rings at reconnections events. Furthermore, we analyse the post-reconnection behaviour of these vortex rings and assess their capability of dissipating energy and transfering vortex line length in space. Finally, we estimate the importance of vortex ring emission for energy dissipation in typical superfluid experiments and conclude that the Kelvin-wave cascade seems the most plausible scenario for high density tangles.

Large-scale vortical motions in thermal counterflow around an obstacle

J. Bertolaccini (a) , P.-E. Roche (b), **E. Lévêque (speaker)** (a,c)

(a) Ecole normale supérieure de Lyon, Lyon, France

(b) Institut Néel, Grenoble, France

(c) Ecole centrale de Lyon, Lyon, France

When a cylinder is placed in a counterflow channel, large-scale vortical structures appear on both sides of the cylinder, as originally vizualised by Zhang & Van Sciver (Nature Physics 1, 36-38 (2005)). Within the framework of the two-fluid model, we investigate the role played by the mutual friction (between the normal-fluid and superfluid components) in the apparition and dynamics of these structures.

Dynamics of the Density of Quantized Vortex-Lines in Superfluid Turbulence

V. S. L'vov

in collaboration with

D. Khomenko, L. Kondaurova, P. Mishra, A. Pomyalov and I. Procaccia

The Weizmann Institute of Science, Israel

Abstract

The quantization of vortex lines in superfluids requires the introduction of their density $\mathcal{L}(\boldsymbol{r},t)$ in the description of quantum turbulence. The space homogeneous balance equation for $\mathcal{L}(t)$, proposed by Vinen on the basis of dimensional and physical considerations, allows a number of competing forms for the production term $\mathcal{P}$. Attempts to choose the correct one on the basis of time-dependent homogeneous experiments ended inconclusively. To overcome this difficulty we announce here an approach that employs an inhomogeneous channel flow which is excellently suitable to distinguish the implications of the various possible forms of the desired equation. We demonstrate that the originally selected form which was extensively used in the literature is in strong contradiction with our data. We therefore present a new inhomogeneous equation for $\mathcal{L}(\boldsymbol{r},t)$ that is in agreement with our data and propose that it should be considered for further studies of superfluid turbulence.

Superfluid turbulence near the intervortex scale

Sergey Nazarenko

Warwick

Based on work with

Laurent Boué, Victor S L'vov, Yotam Nagar, Anna Pomyalov, Itamar Procaccia

I will discuss some physical ideas about the effect of the finite temperature and rotation onto the superfluid turbulence near the intervortex scale. Specifically, I will address the question whether the bottleneck accumulation at such scales should be expected to be reduced or enhanced by these factors. I will argue that there are two competing effects impeding the energy cascade to the smallest scales: weak Kelvin waves expected at low temperatures and suppressed vortex reconnections arising in presence of strong rotation or other setups with strong polarisations of the vortex tangle. I will discuss how we could detect these effects experimentally.

Experimental and numerical suggestions based on the theoretical models.

Sergey K. Nemirovskii
Institute of Thermophysics, Novosibirsk, Russia
and Novosibirsk State University, Novosibirsk

Although there is no developed theory of quantum turbulence (QT) so far, rather the isolated modest separate fragments of the whole process exist, they bear a series predictions which can serve as ideas for experimental and numerical proposals. In the talk I present a number of suggestions on experimental and numerical study of QT, which follow from the theoretical models developed recently.

Thus, for example, the theory describing quantum turbulence as a network of splitting and merging vortex loops gives a series of predictions, which can be checked in experimental and numerical studies. In particular, it predicts that depending on the temperature, either the cascade-like breakdown of vortex loops dominates, or, on the contrary, the cascade-like fusion prevails. At low temperature, when cascade-like breakdown of vortex loops dominates, the well developed turbulent state arises. At higher temperature, the cascade-like fusion prevails, that leads to the degeneration of the QT. Another suggestion concerns the rates of fusion or splitting as functions of lengths of loops. This can confirm (or refute) the random walking model of vortex tangle (VT). One more proposal concerns the determination of the size distribution of the loops, constituing the VT from monitoring of the emitted (from the turbulent domain) vortex loops. Theoretical results on the correlation characteristics of vortex filaments (e.g. correlation between tangent vectors) are exclusively important and they also can be checked.

There are also several suggestion concerning the dynamics of single vortex filaments (ignoring reconnections), both for the small perturbations (Kelvin waves (KW) theory), and for large chaotic distortions of vortex loops. Although current calculations of the KW spectra ignore the reconnections, the latter (in the real VT) can be considered, as a random stirring of filament, hence they can modify spectrum. Therefore it would by extremely important to calculate spectra for the real VT, and compare them with the spectra from the single line. The difference is very informative for viewing of the QT properties.

The number of proposals are related with the Schwarz kinetic equation for the distribution function of the line length $\lambda(R, \theta, t)$, where R is radius of curvature of the line element and θ is its orientation in space. Schwarz concluded that the structure parameters (polarization coefficients, curvature factor, etc.) do not depend on the applied counterflow velocity (which is the puzzling fact itself), but depend on the temperature, obeying equation of the diffusion-type behavior. That implies that changing the temperature T , one would predict and measure the temporal behaviour of the structure parameters, e.g. the polarization with the use of the second sound method.

The hydrodynamics of superfluid turbulence (HST), the theory which unify Vinen equation with the classical Landau two-fluid model, gives great scope for numerical and experimental investigations. For instance, the HST predicts, that the interaction of the (non-transverse) second sound waves with the QT is not just reduced to the sound attenuation, but results in a variety of diverse processes. These would be dispersion, anisotropy of damping (even for isotropic turbulence), coupling between the transverse and longitudinal sound waves etc. Similarly, a wealth of information about the structure and dynamics of QT can be extracted from a study of the thermal pulses that generate vortices and interact with these "own" vortices (back reaction). In addition, the study of propagation of the turbulent domain (e.g. velocity), is very informative process about the QT structure and dynamics

The important question of the different arrangement of QT, namely whether it is a set of vortex bundles, Vinen disordered state, or mix of these two forms can be experimentally checked from the study of fluctuations of the Vortex Line Density (VLD) $< \delta\mathcal{L}(\omega)\ \delta\mathcal{L}(-\omega) >$ in turbulent flows. The different forms of QT give various dependencies of these quantities on frequency ω. This conclusion may serve as a basis for the experimental determination of what kind of the turbulence is implemented in different types of generation of QT.

One more series of proposal concerns the combined flow when rotation and QT coexist. This topic has not been very much studied. We would like to attract the attention to one model, describing relaxation mechanism, which appears due to retardation between angular velocity of the container and angular momentum. This model predicts the period shift and the extra dissipation of torsion oscillations, which easily can be detected in the experiment.

In a bit more details, the theses stated in this abstract can be read in paper by author [1], Section 10.

The work was supported by the grants N 15-02-05366 and N 13-08-00673 from RFBR.

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The T1 transition in counterflow: puzzle and geometrical artefact

J. Bertolaccini (a) , E. Lévêque (a,b), **P.-E. Roche (speaker)** (c)

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(b) Ecole centrale de Lyon, Lyon, France
(c) Institut Néel, Grenoble, France

The T1 counterflow transition has been studied for half a century and more than a dozen of theoretical models have been proposed to explain it. Still, experimentalists failed to conclusively decide among them due to unexplained scattering of measurements. Firstly, we will shortly review contradictory models and measurements of the T1-transition velocity threshold. Secondly, we propose a new criterion supported by numerical simulations, which suggests that part of the experimental scattering could result from a simple geometrical artefact.

Micro-machined cantilever anemometer: Measurements in cryogenic turbulence.

Eléonore Rusaouen

Lyon

As cryogenic turbulence involves a large range of different length scales and the environmental conditions are binding, it is necessary to imagine new kinds of sensors. Here, I will present a new silicon-based anemometer, typical length 375 microns, which provides the signed velocity at low temperatures. It operates from room temperature down to liquid helium temperature. This probe is developed within the EuHit project.

Imaging quantum turbulence in ^{3}He-B: Do spectral properties of Andreev reflection reveal properties of turbulence?

Y. A. Sergeev[a]

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[d]School of Mathematics, Bristol University, UK

The choice of experimental techniques available for measurements of quantum turbulence at temperatures close to absolute zero is rather limited. For example, the second sound and the PIV/PTV techniques necessarily require the presence of the normal fluid and, therefore, are not applicable at $T \to 0$. One of alternative experimental techniques for studying quantum turbulence at very low temperatures is provided by measurements in ^{3}He-B.

Turbulence in superfluid ^{3}He can be imaged by the Andreev reflection of ambient thermal quasiparticle excitations, facilitating passive visualization near absolute zero. Here we combine experiments and numerical simulations to analyze the total Andreev reflection from the vortex tangle, and to reveal the connection between the spectral properties of turbulence and those of Andreev scattering. Our results show that the fluctuations of the vortex line density and of the Andreev reflection are well correlated. However, we found that the spectral densities of these fluctuations behave differently: for large scale flows that polarize vortex lines the frequency (f) spectrum of the line density scales as f^{-3}, while that of Andreev reflection behaves as $f^{-5/3}$. Interestingly, the scaling is reversed for an unpolarized tangle. We analyze the underlying physical mechanisms responsible for these scalings.

In discussion, we will address the following questions:

- Do spectral properties of Andreev reflection reveal those of quantum turbulence in the zero-temperature limit?
- How do screening mechanisms of Andreev reflection affect the measurements and their interpretation?
- Can the Kolmogorov-type quantum turbulence be distinguished from the Vinen turbulence by their Andreev reflection signatures?
- Can the coherent structures such as vortex bundles be identified by their Andreev reflection signatures?

Recent Results on Quantum Turbulence in 4He Obtained UsingVisualization and Oscillating Objets in Prague

Ladislav Skrbek

Prague

We review our recent investigations of cryogenic flows and quantum turbulence in superfluid 4He. First, we discuss our visualization studies, in the temperature range T > 1.2 K, of the Lagrangian dynamics of solid hydrogen/deuterium particles of micron size and the added mass effects in thermal counterflow and our results, obtained in both classical and quantum flows of liquid helium due to oscillating cylinder of rectangular cross-section. Second, based on our computer simulations, we show that interaction of seeding particles with quantized vortices and with the normal fluid flow in thermal counterflow could under some experimental conditions could pose problems in their interpretation. Third, we review our recent results, for T>10 mK, on transition to quantum turbulence in flows due to various vibrating objects, in particular, in revisited experiments with torsionally oscillating discs. Additionally, we use second sound to directly detect the vortex tangle in the vicinity of a vibrating quartz fork.
We acknowledge the support of GAˇCR P203/11/0442 and 203/14/02005S.

Turbulent drag on quartz tuning forks in superfluid 4He.

Viktor Tsepelin

Lancaster

We present measurements of the turbulent drag force on quartz tuning forks oscillating in superfluid 4He. Tuning forks were custom made from a 75-μm-thick wafer. All forks have identical prong widths and prong spacing, but different lengths to give different resonant frequencies. We have used both the fundamental and overtone flexure modes to study turbulence nucleation over a broad range of frequencies $f=\omega/2\pi$ from 6.5 to 300 kHz. Optical measurements show that the velocity profiles of the flexure modes are well described by a cantilever beam model. The onset of quantum turbulence has square root frequency dependence of the critical velocity is $vc\approx\sqrt{}0.7\kappa\omega$, where κ is the circulation quantum. Our results agree with earlier studies carried out at lower frequencies. Our measurements show that turbulent drag has a weak frequency dependence as a function of scaled velocity v/vc.

Review of numerical works of thermal counterflow -Route to inhomogeneous quantum turbulence

Makoto Tsubota
Osaka

The numerical simulation based on the vortex filament model (VFM) was pioneered by Schwarz, and the recent visualization in thermal counterflow makes the simulation go towards inhomogeneous quantum turbulence. I would review the developments of the numerical works.
1. Schwarz performed the simulation of the VFM in thermal counterflow to obtain the statistically steady states (1). The obtained results showed good agreements with typical observations. However, his simulations had some difficulties. Most of his simulation were done under the periodic boundary conditions and using the Localized Induction Approximation (LIA) neglecting the intervortex interaction. Thus he introduced some artificial mixing procedure in order to get the statistically steady states. Recent numerical works of the full Biot-Savart law overcame the difficulty and succeeded in obtaining the statistically steady states without any artificial procedure (2).
2. Almost all previous simulations were performed for homogeneous cases. However, the recent visualization experiments found that increasing the heat flus changed the profile of the normal fluid from the Poiseuille flow to the tail-flattened flow, and turbulence (3). The results show that flow is inhomogeneous strongly affected by the geometry. Recently we performed the simulation in a square channel supposing that the normal flow is Poiseuille or tail-flattened to obtain inhomogeneous vortex tangle (4).

(1) K. W. Schwarz, Phys. Rev. B 38, 2398 (1988). (2) H. Adachi, S. Fujiyama, M. Tsubota, Phys. Rev. B 81, 104511 (2010). (3) A Marakov et al., Phys. Rev. B 91, 094503 (2015). (4) S. Yui, M. Tsubota, arXiv: 1502.06683.

Lagrangian property of particle motions in He4 ; comparison with classical turbulence

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We add the small parties in He4 and visualized their motions. The particles are made of solid hydrogen whose diameter is the order of micron. In a counter flow, changing the heat flux and bath temperature, Lagrangian velocity and accelerations are computed by analyzing the visualized imaged through PTV technique. The probability density functions of acceleration shows the nearly stretched exponential shape. It indicates the similar characteristics in classical turbulence. We compared the detail of them and discuss their property.

The decay of counterflow turbulence in superfluid ^{4}He

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Thermal counterflow turbulence in superfluid ^{4}He above 1K has been studied for many years with second sound, which serves to measure the density of quantized vortex lines in the turbulent flow. It has long been recognized that the decay of this density when the heat flux is turned off exhibits interesting and unexpected features, most notably a decay with time as $t^{-3/2}$ at large times and periods when the decay is replaced by an apparent growth at shorter times. The decay at large times is thought to be associated with the decay of two-fluid coupled eddies with sizes limited by the size of the channel, although it has not been understood how such eddies are formed. There has been speculation about the features at smaller times, but no firm conclusions. Recent interesting and often puzzling observations have shown how these features are affected by the superposition of a net mass flow, as will be described by Babuin at this workshop. The development of a new visualization technique by Guo *et al*, described by Guo at this workshop and based on the use of metastable He_2 excimer molecules to trace the motion of the normal fluid, is allowing us to address these problems in more detail than has hitherto been possible. It can be shown that very soon after the counterflow is turned off the motion of the two fluids is expected to become strongly coupled, so that the excimer molecules then trace this coupled motion, allowing us to follow how the intensity and energy spectrum of any coupled turbulence evolves in time. The presentation will summarise how these new experimental studies, combined with some computer modelling (by Emil Varga), are leading us to a better understanding of the decay of quantum turbulence.