

# Numerical simulation of quantum turbulence in superfluid helium -Inhomogeneous quantum turbulence-

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## Summary

We review the recent numerical studies of quantum turbulence in superfluid helium. The numerical simulation based on the vortex filament model was pioneered by Schwarz, and has revealed lots of physics in thermal counterflow of superfluid helium. Almost all previous numerical works supposed that the system was homogeneous. However, the recent visualization experiments found that the normal fluid flow was inhomogeneous strongly affected by the geometry. Motivated by the experiments, we performed the simulation in a square channel under the inhomogeneous normal fluid flow to study inhomogeneous vortex tangle. Then we found the logarithmic velocity profile of a superfluid flow.

## 1 Introduction

Quantum turbulence (QT) in thermal counterflow of superfluid  $^4\text{He}$  has been studied more than half century. Any rotational motion of superfluid is sustained by quantized vortices, which have the quantum circulation  $\kappa = h/m_4$ , where  $h$  is Planck's constant and  $m_4$  is a mass of a  $^4\text{He}$  atom. Since the core of a quantized vortex is extremely thin, namely the order of atomic scale, a vortex filament model works well in this system. A random tangle of quantized vortices is a typical example of QT. A characteristic of QT is that vortices are definite and well-defined as elements of turbulence, which differs from eddies in classical traditional turbulence.

The numerical simulation of the vortex filament model in superfluid  $^4\text{He}$  was developed by Schwarz [1], revealing that counterflow turbulence was a self-sustained vortex state caused by the competition between the excitation due to the external flow and the dissipation by the mutual friction. However, most numerical works used the Localized-Induction Approximation (LIA) neglecting the interaction between the vortices, and needed some artificial mixing procedure in order to sustain a homogeneous vortex tangle under the periodic boundary condition. Adachi *et al.* performed the simulation not using the LIA but by the full Biot-Savart integral, succeeding in obtaining statistically steady states without any artificial procedures [2].

These previous studies assumed that the system was uniform, because there were no information on how the system was affected by the geometry. By using a laser-induced fluorescence technique, Marakov *et al.* observed an inhomogeneous velocity profile of a normal fluid component in a square channel [3]. Motivated by the experiment, the scientists have started to get interested in inhomogeneous QT in a channel. Baggaley *et al.* numerically studied the inhomogeneous vortex tangle between two parallel plates under the prescribed Hagen-Poiseuille flow [4].

## 2 Inhomogeneous quantum turbulence in thermal counterflow

We study numerically inhomogeneous vortex tangle in a square channel [5] supposing that the normal fluid flow is prescribed to be Hagen-Poiseuille flow or tail-flattened flow [3]. The vortex tangle shows a characteristic space-time oscillation. Vortices are denser near the channel walls (shown in Figure 1), suggesting turbulent boundary layer of superfluid.

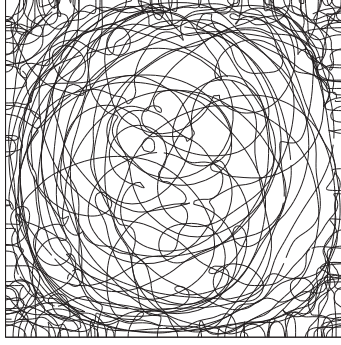


Fig. 1: Typical inhomogeneous vortex tangle viewed along the flow direction in a square channel.

### 3 Logarithmic velocity profile

Turbulent boundary layer reminds us of the log-law, namely the logarithmic velocity profile. We study the vortex dynamics under pure normal Poiseuille flow between two parallel plates [6]. When we calculate superfluid velocity field due to the inhomogeneous vortex tangle, it shows the logarithmic velocity profile as shown in Figure 2. This is the first numerical confirmation of the log-law in QT.

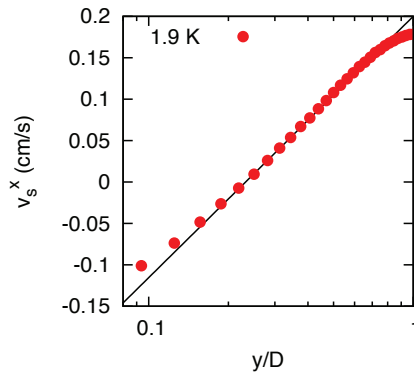


Fig. 2: Logarithmic velocity profile of quantum turbulence in thermal counterflow.

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