Quantum turbulence in Helium II (at very low temperature)
Lattice-Boltzmann numerical simulations of the two-fluid model
Influence of boundary conditions on the stability of superfluid counter-flows

PhD research project to be supervised
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Location of the thesis: Laboratoire de Physique de l'ENS de Lyon, 46 Allée d'Italie, 69364 Lyon cedex 7 (France)

Funding very probable

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General scientific context:

Helium-II at (finite) temperature below the transition $T_\lambda \approx 2.17$ K can be described as the superposition of two interacting fluids. A normal fluid which has non-zero viscosity and an inviscid superfluid, in which vorticity is confined to quantized vortices [1]. The large-scale dynamics of these two co-penetrating fluids obey respectively the Navier-Stokes and Euler equations (at low Mach number) coupled together by a mutual friction force that encompasses interactions between the quantized vortices and thermal excitations of the normal fluid. This is the general framework of the so-called *two-fluid model* initiated by Landau and Tisza [2].

Like in classical fluids, turbulent dynamics can be generated in superfluid Helium II. This is referred to as quantum (or superfluid) turbulence in the literature. Since the pioneering experiments by Vinen about half a century ago [3], quantum turbulence has been investigated mostly experimentally with the motivation to examine *to what extent quantum turbulence resembles or differs from classical turbulence in ordinary fluids*. Related theoretical and numerical works rely mainly on simplified one-way coupling (no back reaction) between the normal fluid and the superfluid, *e.g.* in the vortex-filament model based on works by Schwarz [4]; wall boundary conditions are also often ignored. These studies have yielded significant progress; however, we are still a long way from a full understanding. In this regard, it is admitted that *improved numerical simulations are needed*.

During the last three years, we have been involved in two-way coupling simulations of the two-fluid model in the configuration of homogeneous and isotropic quantum turbulence (therefore discarding wall boundary effects). New results concerning the joint distributions of normal and superfluid kinetic energy among Fourier modes have already been published [5]. Today, we are motivated to investigate further quantum turbulence (by means of simulations of the two-fluid model) and address in particular wall-boundary effects. This point has never been examined but is expected to play an important role, especially in the onset of counter-flow turbulence [6a]. These numerical simulations could then participate to the current growing interest in counter-flow turbulence, which is aroused by new experimental visualization techniques [6b].

Accordingly, *the present PhD proposal aims at developing numerical simulations of the two-fluid model that includes wall boundary condition* (free slip, no-slip and in-between conditions to account for vortex pinning at the walls). The Lattice-Boltzmann scheme is expected to provide an adequate framework for the discretization of the two-fluid equations and the implementation of boundary conditions. Simulations of steady-state and decaying counterflow turbulence (through a channel) will be of particular interest.

While traditional methods start with a continuous description of the fluid at a macroscopic level, *e.g.* the Navier-Stokes equations, the Lattice-Boltzmann method (LBM) considers the fluid at a kinetic level [7]. Therefore, the fluid is viewed as groups of fictive particles that collide and propagate on a lattice so that the correct dynamics is recovered at a macroscopic level. Due to its particulate nature and its local dynamics, the LBM has several advantages over other conventional methods, especially in dealing with complex boundary conditions, incorporating multi-physics interactions, and the parallelization of the algorithms. Our group is familiar with the Lattice-Boltzmann method and is already involved in the development of simulations based on the LBM for classical turbulence.

Finally, this project will be hosted at the *Centre Blaise Pascal – ENS de Lyon*, which offers a favorable scientific and material environment for projects in numerical science (http://www.cbp.ens-lyon.fr). In particular, the project will benefit from access to the *local high-performance computing platform* PSMN (http://www.psmn.ens-lyon.fr).

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[7] S. Chen and G. Doolen, Lattice Boltzmann Method for Fluid Flows, *Annual Review of Fluid Mechanics* **30** (1998) 329-364

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Objectives of the PhD:

- derivation of discretized equations of the two-fluid model in the Lattice-Boltzmann framework – treatment of boundary conditions.
- development of a parallel solver for the three-dimensional dynamics (in C++).
- tests and validation: the wealth of experience and information available about instabilities in the classical Taylor-Couette flow of Helium-II makes it an ideal test bed [8].
- study the (experimentally observed) T1-T2 transition in counterflow superfluid turbulence [6].
- numerical results will be compared with specially-designed experiments performed in parallel at the Institut Néel.

Required skills:

- statistical mechanics (Boltzmann equation), fluid mechanics
- basics of programming is enough

Existing Collaborations on the topic:

- **Ens de Lyon** : B. Castaing, L. Chevillard, J. Salort
- **Intitut Néel** : B. Chabaud, M. Gibert
- **CEA Grenoble** : P. Diribarne