PhD position
Waves and turbulence in rotating superfluid helium-4

Motivation Near absolute zero, liquid helium-4 enters a superfluid state known as He II where it displays unique hydrodynamical properties. At finite temperatures between about 1 and 2 K, He II can be seen as a mixture of a viscous normal fluid and a superfluid without viscosity, whose rotational degrees of freedom are concentrated on so-called quantum vortices with atomic-scale thickness and quantised intensity. When He II is set in rotation, these quantum vortices tend to align with the rotation axis and form a highly regular vortex lattice as initially predicted by Feynman [1]. Moreover, when perturbed by external mechanisms, rotating He II can host a variety of wavelike motions, such as inertial waves propagating through the fluid as in classical rotating flows, but also waves which propagate on one or more quantum vortices. As the perturbation is intensified, these waves can destabilise and lead to a disordered state, eventually resulting in some form of rotating quantum turbulence.

The formation of a regular vortex lattice and its destabilisation by an external heat source have been recently visualised in state-of-the-art experiments at Institut Néel (Grenoble) [2,3]. In these experiments, small particles are injected onto a rotating tank filled with superfluid helium-4 [Fig. 1(a)]. These particles then get trapped on quantum vortices, enabling their direct visualisation. By applying a moderate heat input at the bottom of the experiment, the initially regular vortex lattice deforms and displays stable wavelike motions clearly visible in Fig. 1(b). These deformations are a result of the interaction between quantum vortices and the viscous normal fluid. Indeed, in superfluid helium, applying a heat flux results in the relative motion between the superfluid and the normal fluid components, as the latter evacuates the heat. This counterflow phenomenon, which has no analogue in classical fluids, can amplify the interaction between quantum vortices and normal fluid and potentially lead to vortex instabilities.

As the heat flux is further increased, the perturbed lattice destabilises and ultimately breaks leading to a form of turbulent state. However, both the precise destabilisation mechanisms

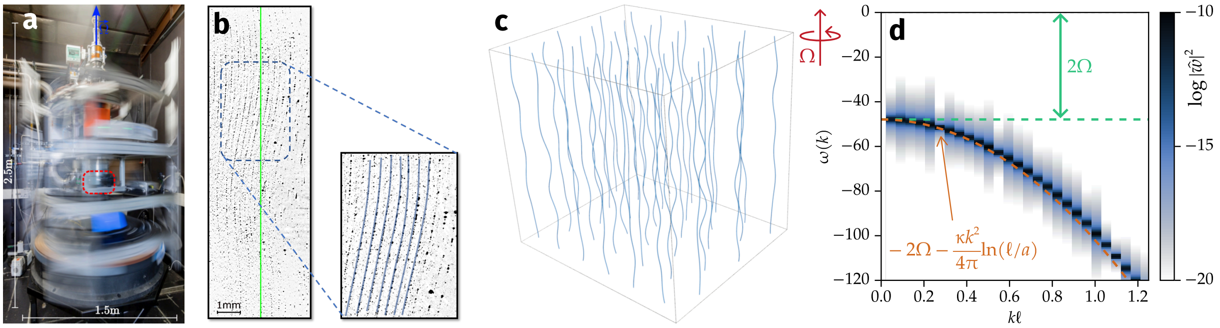

Figure 1. Vortex waves in rotating superfluid helium. (a) Rotating CryoLEM experiment at Institut Néel. **(b)** Experimental visualisation of a regular lattice of quantum vortices perturbed by an external heat source. **(c)** Simulation of a quantum vortex lattice in rotating superfluid helium using the VortexPasta.jl solver. **(d)** Spatio-temporal spectrum of waves propagating on quantum vortices. The dotted orange line is the theoretical dispersion relation associated to Kelvin waves propagating along the vortices in rotating helium.

and the resulting turbulent regime are still poorly understood. This is in part because, as the turbulent regime is reached, direct vortex visualisation becomes very challenging, since vortices collide leading to reconnections, and particles are likely expelled from the vortices. Besides, understanding the destabilisation mechanisms requires a detailed description of the intricate two-way interactions between normal fluid and quantum vortices, which is mostly inaccessible to experimental measurements. Therefore, numerical simulations accounting for these interactions are needed to interpret the experimental observations and gain further insights on the dynamics of rotating superfluid helium.

Objectives The objective of this PhD project is to investigate the dynamics of quantum vortices in rotating He II using numerical simulations. We will first focus on the zero temperature limit where the normal fluid is absent, and identify the different wave motions that can propagate on one or more quantum vortices in rotating helium-4 as predicted theoretically [4]. This includes Kelvin waves propagating longitudinally along the vortices [Fig. 1(c-d)] and also Tkachenko waves which correspond to lattice deformations in the transverse direction. We will then perturb the system by applying an external vortex velocity mimicking a mechanical forcing [5], in order to investigate the turbulent regimes resulting from the combination of forcing and rotation at zero temperature. In particular, we will characterise the possible role of waves in rotating quantum turbulence, and seek for the possible emergence of an inverse energy cascade towards large scales as observed in classical rotating flows.

In the second part of this project, we will investigate the finite-temperature case, more relevant to experiments, where quantum vortices interact with a normal fluid. We will first characterise the destabilisation of the rotating vortex lattice due to a thermal forcing, with the aim of explaining existent experimental measurements and identifying the relevant instability mechanisms. Our numerical results will be compared quantitatively with experimental measurements at Institut Néel. Then, we will study the fully turbulent regime due to an intense heat flux in the presence of rotation. We will characterise the spatial structure of this form of turbulence, which is expected to be highly anisotropic, and perform comparisons with experimental particle tracking measurements at Institut Néel in the turbulent regime.

Methodology We will perform numerical simulations of the vortex filament model (VFM) [6], which is relevant for describing quantum vortex dynamics at macroscopic scales. The VFM describes quantum vortices as spatial lines which collectively induce a velocity field throughout space according to the Biot–Savart law, which expresses the instantaneous velocity of a single vortex point as an integral over all vortex filaments in the system. One limitation of this model is that directly evaluating all vortex velocities becomes very costly as the number of vortices increases. We have recently developed a novel method, specifically adapted to periodic domains, which dramatically accelerates such evaluations by using fast Fourier transforms [7], and which can also accurately account for global rotation of the system. This approach is implemented in the open-source GPU-accelerated VortexPasta.jl solver[1], and has recently enabled the simulation of isotropic quantum turbulence (in the absence of rotation) at unprecedented turbulence levels [5]. To investigate finite-temperature effects, VortexPasta.jl will be coupled to a Navier–Stokes solver describing the normal fluid, following a well established two-fluid modelling approach [8].

Expected profile The candidate must have a Masters degree in fluid mechanics, physics, applied mathematics or a related field. Knowledge of turbulent flows and vortex dynamics will

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[1] https://github.com/jipolanco/VortexPasta.jl

be highly welcome. A solid programming experience is also required. The candidate should have good oral and written communication skills in English.

Supervision The project will be co-supervised by Juan Ignacio Polanco (CR CNRS, LEGI) and Mathieu Gibert (CR CNRS, Institut Néel). The project will be mainly carried out within the MOST team (Turbulence Modelling and Simulation) at LEGI (Laboratory for Industrial and Geophysical Flows) in Grenoble, with frequent visits to Institut Néel where the experimental work is performed.

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Application deadline 27 May 2026

Start date 1 October 2026

Project duration 36 months

Contacts and application For more information, send an e-mail to `juan-ignacio.polanco@univ-grenoble-alpes.fr` and `mathieu.gibert@neel.cnrs.fr` including a CV. Applications should be done via the ADUM platform. The recruitement process is in accordance with the Université Grenoble Alpes OTM-R (Open Transparent Merit-based Recruitement) policy.

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