Proposition de stage de M1

à l'Institut de Physique de Nice
CNRS & Université Côte d'Azur

Superfluid flow past an antisymmetric obstacle

Theoretical study

General context.— Superfluidity [1] is the ability of a quantum fluid to flow without dissipation below a critical velocity. Initially observed in liquid helium, it has since been demonstrated in many systems, such as Bose–Einstein condensates of ultracold atoms, semiconductor microcavity polaritons, as well as fluids of light. These platforms now provide a unified framework for the study of quantum hydrodynamics.

From a theoretical point of view, the critical velocity was introduced by Landau from the spectrum of elementary excitations of the fluid. Although fundamental, this criterion is strictly valid only for weak and idealized perturbations. In practice, the flow of a superfluid is often disturbed by localized obstacles of large amplitude, leading to nonlinear mechanisms of superfluid breakdown (emission of solitons, vortices, shock waves).

Since the pioneering works of Frisch, Pomeau and Rica [2] and Hakim [3], numerous studies have analyzed the critical velocity in the presence of obstacles in one and two dimensions (see [4, 5] for reviews). However, most of these works focus on symmetric obstacles (barriers, wells, disks), and the influence of the obstacle shape remains largely unexplored. In particular, very little is known about so-called dipolar obstacles, which are antisymmetric along one spatial direction. This project proposes to systematically investigate the effect of such an obstacle on the stability of a superfluid flow.

Objectives.— The main objective of this project is to study the stability of a superfluid flow in the presence of an antisymmetric obstacle, and to understand how this asymmetry modifies the mechanisms responsible for the breakdown of superfluidity. To this end, we will consider the nonlinear Schrödinger equation, also known as the Gross–Pitaevskii equation. We will first analyze the one-dimensional situation, for which an exact solution can be found for a model obstacle and numerical simulations can be carried out straightforwardly. In two dimensions, the problem will be addressed through numerical simulations of the Gross–Pitaevskii equation. Particular attention will be paid to the formation of vortices and their role in the loss of superfluidity in the presence of an antisymmetric obstacle.

This project will allow the student to become familiar with analytical and numerical tools of quantum hydrodynamics and to explore a problem that remains largely open.

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[1] A. J. Leggett, *Superfluidity*, Rev. Mod. Phys. **71**, S318 (1999).

[2] T. Frisch, Y. Pomeau, and S. Rica, *Transition to dissipation in a model of superflow*, Phys. Rev. Lett. **69**, 1644 (1992).

[3] V. Hakim, *Nonlinear Schrödinger flow past an obstacle in one dimension*, Phys. Rev. E **55**, 2835 (1997).

[4] J. Huynh, M. Albert and P.-É. Larré, *Critical velocity for superfluidity in the one-dimensional mean-field regime: From matter to light quantum fluids*, Phys. Rev. A **105**, 023305 (2022).

[5] J. Huynh, F. Hébert, M. Albert and P.-É. Larré, *Critical velocity of a two-dimensional superflow past a potential barrier of arbitrary penetrability*, Phys. Rev. A 109, 013317.