Nonlinear processes in quantum fluids

Understanding the nonlinear dynamics of quantum systems is crucial for advancing both fundamental physics and practical applications in quantum technologies. Various systems, from ultracold atomic vapors to superfluid helium, exhibit rich nonlinear structures such as solitons, vortices and shock waves, which provide insights into complex quantum behaviors. This internship project aims to explore the interplay between nonlinearity and quantum effects, particularly focusing (i) on the dynamics of interacting bosons in one dimension and (ii) the formation of vortex-antivortex pairs in two-component Bose-Einstein condensates.

The internship corresponds to a theoretical physics project and is intended to be followed by a PhD, during which one will aim to stay in close contact with experimental issues.

After a period dedicated to getting acquaintance with the necessary theoretical tools (Riemann method for hyperbolic partial differential equations), the student will study the nonlinear spreading of a slice of interacting bosons in one dimension. The idea being to reproduce the configuration studied in an experiment recently performed at IOGS.

Another aspect of this PhD project focuses on the formation of vortices in two-dimensional superfluids. In these systems, vortices possess a quantal topological charge known as vorticity. The conservation of this charge necessitates that vortices typically appear in pairs with opposite vorticity, referred to as vortex/antivortex pairs. Additionally, vortices are characterized by another topological index: the Poincaré index. The conservation of both vorticity and the Poincaré index implies that the creation of a vortex/antivortex pair is accompanied by the emergence of other critical points, such as phase extrema or saddles. A key objective of this PhD project is to investigate various scenarios of vortex/antivortex formation in a two-component Bose-Einstein condensate. It is anticipated that new topological charges will need to be considered, potentially leading to novel bifurcation processes for the formation of vortex pairs. Given that the onset of turbulence is associated to the formation of a large number of vortices, understanding these newly identified topological constraints may also illuminate the pathways to quantum turbulence in two-component superfluids.