Interaction control in coupled two-component condensates

Ultracold quantum gases are model quantum many-body systems mainly because of the simplicity of the interactions that are dominantly happening as two-body collisions which can be accurately described by contact interactions. Due to the diluteness of the gas, three-body interactions are usually negligible. In this context, our group is experienced in the production of potassium 39 Bose-Einstein condensates in a few seconds and in the control of the scattering length which characterizes two-body interactions.

Recently, we work with an innovative method to control interparticle interaction. More precisely the method is based on a condensate in a dressed state composed of two spin states that are coherently coupled through a radio-frequency. It not only permits the control of the two-body interaction but also introduces three-body interactions (PRL **128**, 083401 (2022)). Three-body interactions can be made to play a dominant role in the condensate dynamics. We have for example observed the collapse of the Bose-Einstein condensate induced by these interactions.

The current interest of the experiment is the further study of three-body interaction effects in one-dimensional configurations. 1) Three-body energy per particle scales as $1/r^2$, where r is the condensate size. Since this scaling is the same as the kinetic energy term, the mean-field description of the condensate with pure three-body interaction is scale invariant and from one solution, one can find other solutions with different sizes. For attractive three-body interactions, a predicted family of solutions is composed of solitons (self-trapped solutions) that occurs only for a given atom number. These solitons have similar properties as Townes solitons first introduced in non-linear optics. 2) The 1D Bose gas with pure two-body interactions have integrable dynamics (meaning that it does not thermalize, due to numerous conserved quantities) that is a subject of on-going research. Adding three-body interactions in a controlled way, we will study the progressive breaking of the integrable behavior. 3) An alternative subject could be linked to the weaker repulsive three-body interactions that appears in the same systems due to quantum fluctuations (PRL 127, 203402 (2021)). Together with attractive two-body interaction, three-body interaction may also lead to the formation of quantum droplets which are yet another type of self-trapped condensates.

In the context of a M2 internship, we propose to develop another tool in our setup: a Raman laser system (at 532 nm). It will permit coupling of the two spin states through a two-photon optical transition. This has the advantage to allow to work at large magnetic field where the two spin states of interest are not coupled by a radio-frequency and where the transition is less magnetic field sensitive. Second, lasers can be spatially patterned and the coupling can be made position dependent, allowing a position dependent interaction. Finally, this opens the possibility of momentum dependent coupling if the two Raman beams are not copropagating. This leads to velocity dependent interaction and to possible formation of a supersolid phase. The internship could continue with a PhD on interaction control using Raman coupled two-component condensates.

Please contact Thomas Bourdel for more information
E-mail : Thomas.bourdel@institutoptique.fr
Tel : 01 64 53 33 35
Institut d'optique, 2 av. A. Fresnel, 91120 Palaiseau