M2/Thesis in Experimental Quantum Physics
Ultracold atoms at Institut d'Optique

Three-body interactions in coupled two-component condensates: Townes solitons and integrability breaking

Ultracold quantum gases are model quantum many-body systems 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 have demonstrated an innovating method to introduce three-body interactions in Bose-Einstein condensates together with the possibility to reduce the two-body interactions (PRL **128**, 083401 (2022)). In this novel regime, three-body interactions can play a dominant role in the condensate dynamics. We have for example observed the collapse of the Bose-Einstein condensate induced by these interactions. 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. Importantly, potassium 39 offers the possibility to tune both the intra-spin and the inter-spin scattering lengths to different values for the method to work.

In one-dimensional configuration, 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. For higher atom numbers, the condensate collapses whereas for low atom numbers, it expands. These solitons have similar properties as Townes solitons that were recently observed for two-body attractive interactions in 2D (PRL 127, 023603 (2021)). The creation and study of this new type of solitons could be the goal of a M2 internship.

Consequences of three-body interactions in Bose-Einstein condensate could be further studied in the context of a PhD thesis. In particular, 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. 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, this may lead to the formation of quantum droplets which are yet another type of self-trapping condensates.

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