Three-body interactions 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 contact two-body collisions. They are considered as quantum simulators as the flexibility of the experimental settings permits to observe and study a great variety of quantum phenomena. 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 two-body interactions via magnetic field tunable scattering resonances.

Recently, we have discovered an alternative method to control interparticle interaction. More precisely the method is based on a condensate in a dressed state, i.e. a state composed of two coherent spin states that are coupled through a radio-frequency (RF). We have shown that such a system not only permits the control of the two-body interaction but also uniquely introduces three-body interactions (PRL **128**, 083401 (2022)). Three-body interactions can even be made to play a dominant role in the condensate dynamics and we have for example observed the collapse of a Bose-Einstein condensate induced by these interactions. Recent experimental progresses include a digital micro-mirror device that permits to imprint arbitrary potentials to the atoms (accepted in PRA) and an ultraprecise magnetic field stabilization for a better control of the RF dressing (paper in preparation).

The control of three-body interactions is a novel tool that gives access to unexplored effects in the physics of Bose-Einstein-condensates in particular in one-dimensional configurations. 1) Attractive three-body interactions can lead to modulation instability, i.e. the spontaneous apparition of a density modulation. For pure three-body interaction (no 2-body), their dynamics would be uniquely scale invariant. Similarly, special types of scale invariant solitons (condensates that propagates without dispersion) are expected. 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 could study the progressive breaking of the integrable behavior. 3) 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 lead to the formation of a novel type of quantum droplets. This droplets have similar properties as liquid droplets although their stabilization mechanism is linked to quantum fluctuations.

Another possibility offered by our RF dressing is innovative way to time-modulate the two-body interaction in a Bose-Einstein condensate. Such a modulation can create correlated jets of atoms with opposite momenta as first observed in the group of C. Chin in Chicago (Nature 551, 356 (2017)) and with whom we have started to collaborate.

In the context of a M2 internship, the intern would directly work on the main experiment in coordination with an experienced PhD student. She/he is expected to learn how to run our complex experimental apparatus as well as the main theoretical aspects of our research. The goal will be to focus on one of the above topics, taking new data and analyzing them. Ideally, the internship would continue with a PhD thesis.

Financing of the PhD thesis is already secured.

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