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

Position dependent two- and three-body interactions in Bose-Einstein condensates

Our group has expertise in producing potassium-39 Bose–Einstein condensates within a few seconds and in controlling two-body interactions via magnetically tunable scattering resonances. Recently, we have discovered an alternative method to control interparticle interactions. More precisely, this method is based on preparing the condensate in a dressed state, i.e., a superposition of two spin states coupled by a radio-frequency (RF) field. Such a system not only allows for the control of two-body interactions but also uniquely introduces effective three-body interactions (PRL 128, 083401 (2022)). Three-body interactions can even dominate the condensate dynamics: for example, we have observed the collapse of a Bose–Einstein condensate induced by these interactions. Recent progress includes the implementation of a digital micromirror device enabling the imprinting of arbitrary potentials onto the atoms (PRA 110, 043316 (2024)), an ultra-precise magnetic field stabilization system for improved RF-dressing control (Rev. Sci. Instrum. 96, 063201 (2025)), and a theoretical understanding of three-body collision processes within perturbation theory (PRA 111, 053319 (2025)). We have also observed the saturation of interactions as a function of density (arXiv:2507.21849) and are currently attempting to detect the halos associated with three-body collisions in the collision of two Bose–Einstein condensates.

In the future, we aim at implementing Raman coupling (two-photon transition driven by lasers) as a way to modify atom interaction. The development of the laser system (based on telecom lasers with frequency doubling), the combination of two beams at different frequencies (using acousto-optic modulators), and the first tests of such a system (via atomic spin flips) will be the subject of an M2 internship in our team. Such of system enables the position dependent control of the interaction for copropagating laser beams (and velocity dependent interaction for contra-propagating beams). This internship could then continue as a PhD thesis focused on the condensate dynamics in quasi-1D systems. Funding for the PhD thesis is already secured in the framework of a national quantum project on quantum dynamics in 1D systems. The studies may include scale invariant dynamics, the breaking of integrability, and the creation of three-body quantum droplets. All these phenomena are specific to three-body interaction.

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