Internship offer:
Binary dipolar condensates: towards new supersolid states

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Research field

In recent years, the study of long-range interactions has become a central focus within the cold atom community. The manipulation of strongly dipolar species such as erbium (Er) and dysprosium (Dy) has led to the direct observation of supersolidity [1] - a remarkable state of matter where superfluidity or superconductivity coexists with crystalline order. Atomic supersolids share intriguing similarities with pair-density-wave states in superconductors. These latter states arise from the formation of Cooper pairs with non-zero momentum, such as the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) states. Recent evidence suggests that significant pair-density-wave order exists in the phase diagram of cuprate high-temperature superconductors [2].

A comprehensive understanding of supersolidity requires a quantitative investigation of its low-energy excitation spectrum. In one-dimensional (1D) systems, this spectrum consists of two Goldstone modes corresponding to the breaking of two continuous symmetries: one associated with the macroscopic phase and the other with spatial order.

The excitation spectrum of a binary dipolar mixture is even more intricate, offering new and fascinating possibilities. In such systems, the presence of impurities (e.g., a different spin state) can induce crystalline order within an otherwise unmodulated dominant component [3]. This phenomenon arises because the impurity modifies the length scales characterizing atom interactions, *i.e.*, the effective scattering length, a^{eff}, and the dipolar length, $a_{\text{dd}}^{\text{eff}}$, of the miscible system.

Project

In this internship, the selected candidate will address the case of a spin mixture of dysprosium atoms in the Zeeman sublevels $|-8\rangle$ and $|-7\rangle$. For a sufficiently small interspecies scattering length, a_{78}, a 50:50 mixture becomes significantly more dipolar than a spin-polarized sample. In our recent work [4], we determined $a_{88} = 136(8)\,a_0$, $a_{77} = 110(10)\,a_0$, and $a_{78} = 40(20)\,a_0$, which suggests that this "dopant-induced" supersolid state is experimentally feasible.

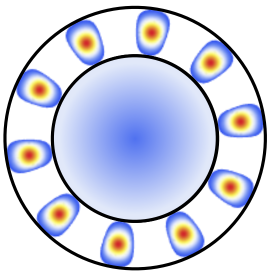

Figure 1: Representation of a supersolid evolving in a ring potential surrounding a superfluid phase. The outer ring displays periodic density modulations characteristic of the supersolid phase. The central region represents the smooth superfluid phase, shown in blue.

In our newly developed dysprosium (Dy) platform [5, 4, 6], he/she will study the excitation spectrum of a "double-supersolid" state, in which the crystalline structures for atoms in $|-8\rangle$ and $|-7\rangle$ are phase-locked. The emergence of crystalline order will be monitored through direct imaging of density modulations. In a subsequent step, thanks to the combination of a micromirror device (DMD) with our Raman setup, the PhD candidate will localize the impurities in a well-defined outer region of the cloud (see Figure 1). This will allow the supersolid to evolve within a ring potential, effectively mapping the system into a linear tube configuration with periodic boundary conditions.

The candidate will then be able to probe the excitation spectrum of this "double-supersolid" system which is expected to display an even richer spectrum than that of conventional supersolids. For instance, the Goldstone mode associated with crystalline order manifests only in the spin component $|-7\rangle$, while the two gauge-symmetry-related Goldstone modes appear in each spin component. At sufficiently low temperatures, the characterization of these modes will allow us to directly measure the superfluid fraction of the supersolid [3, 7].

Looking ahead, the team will investigate the different interaction regimes using the already observed inter-species Feshbach resonance [4], unveiling the rich phase diagram of dipolar spin mixtures. For instance, extending the current project to the non-miscible regime, it should be possible to explore a situation in which the crystalline and superfluid properties of a supersolid are carried by separate spin components, a situation which to our knowledge has never been achieved so far

The project will be conducted on our recently developed dysprosium (Dy) platform [5, 4, 6]. At the start of the project, the candidate will join a team composed of two other PhD students - Julie Veschambre (defense in 2027), and Ethan Uzan (defense in 2028) - and two principal investigators (PIs), R. Lopes and J. Dalibard. He/She will also benefit from collaborative correspondence with the team led by Luis Santos, as well as the ongoing collaborations with O. Dulieu and M. Lepers.

References

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