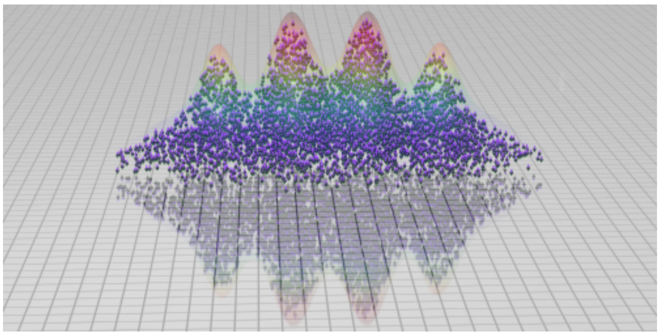
Master project: Creating supersolids with quantum gases

Background: Helium at low temperatures forms a Bose-Einstein condensate and becomes superfluid, where a part of the fluid flows without friction. More than 50 years ago, it has been conjectured that such a superflow could exist even in a crystal, which is then dubbed a supersolid — a counterintuitive state of matter that retains superfluid properties even though the atoms are arranged in a fixed crystalline lattice. In the original proposal, this is because the superfluid component is made up of vacancies or interstitials in the ground state of the lattice. For many years, it was assumed that Helium at very high pressure would form such a supersolid, but this has been shown to be incorrect.

Instead, last year supersolid states have been created at long last in experiments with ultracold quantum gases of atoms that have a strong dipole moment (and hence a particular type of interaction). When cooled to extremely low temperatures, these atoms form a Bose-Einstein condensate with a periodic density modulation of the ground state — this is a supersolid, but it is different from the original model for Helium because the atoms do not form a crystal. Supersolid quantum gases are still poorly understood, but in view of recent experiments their description is now an important theoretical task.



Left: Sketch of the supersolid state in a dipolar quantum gas (image credit: M. Mark/University of Innsbruck). The gas, which is confined in a cigar-shaped external trap, forms a Bose-Einstein condensate with a periodic density profile. Right: The QR code links to a news article by phys.org called "Three teams independently show dipolar quantum gasses support state of supersolid properties", which contains additional links for further reading.

Project proposal: This projects will investigate the phase transition between a superfluid and supersolid state using a semi-classical description for Bose-Einstein condensates known as the Gross-Pitaevskii description. You will discuss instabilities in the excitation spectrum and link them to the phase transition. Since these transitions are explored in various quantum gas setups, there is a chance to compare your findings with experimental results. Send me an email if you want to find out more.

A basic knowledge of quantum mechanics is essential, and background knowledge in condensed matter physics (nearly-free electron model) and thermodynamics (phase transitions) would be very useful. Work on this project will require some numerical work, where the choice of programming language and platform is left to you.

Office space at Physics is expected to be available, but depending on future corona-virus restrictions we might have to work remotely.

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