Thermodynamic phase diagram of an antiferromagnetic gas of spin 1 bosons

Camille Frapolli,[1,*] Tilman Zibold,[1] Andrea Invernizzi,[1] Karina Jiménez Garcia,[1] Bertrand Evrard,[1] Jean Dalibard,[1] and Fabrice Gerbier[1]

[1]*Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-PSL Research University, UPMC-Sorbonne Universités, 5 place Marcellin Berthelot, 75005, Paris, France*

We observe experimentally the magnetic phase diagram of a gas of ultracold sodium atoms at finite temperatures and for several applied magnetic fields. We obtain in particular the critical temperatures at which a Bose-Einstein condensate appears for each spin component. We find, in line with the expectations for an ideal gas, a multi-step Bose-Einstein condensation (BEC) process.

The first transition corresponds to the formation of a spin-polarized condensed phase on top of a "paramagnetic" thermal gas, and is similar to the BEC transition routinely observed for a single-component gas. Depending on the applied magnetic field, the longitudinal magnetization and the atomic density, we observe either one or two additional lower transition temperatures signaling a change in the magnetic order of the condensed phase.

These transitions are strongly affected by atomic interactions (in contrast to the single-component transition temperature, which is only weakly shifted). We also find that the observed magnetic phase diagram for low fields and low temperatures cannot be explained by ideal gas theory, even qualitatively. Antiferromagnetic spin-exchange interactions are essential to understand the observed phases.

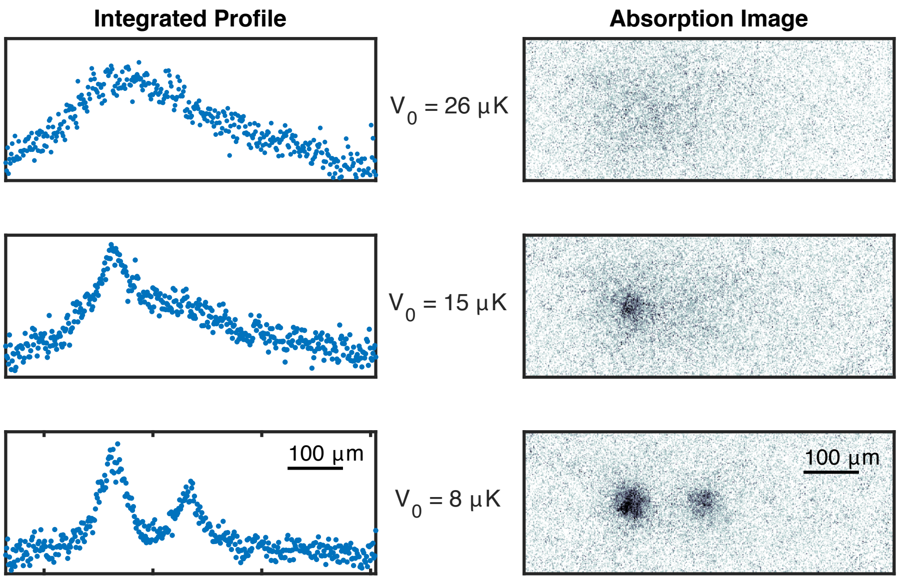

FIG. 1. Pictures showing the density of a spin 1 gas at several temperatures as an illustration for a multi-step Bose-Einstein condensation process. The pictures are taken after a Stern-Gerlach experiment such that the Zeeman components are spatially separated on the pictures (Stern-Gerlach Imaging). Bose-Einstein condensation is indicated by a steep increase in density as compared with a thermal gas. As the temperature decreases, one can see thermal gases in the upper pictures, a BEC for the majority Zeeman component in the middle pictures and a two component BEC in the lower pictures.

* camille.frapolli@lkb.ens.fr