Vlasov-Fokker-Planck description of the magneto-optical trap

R. Romain, D. Hennequin, P. Verkerk
Laboratoire PhLAM Bat. P5 - Université Lille1 France
daniel.hennequin@univ-lille1.fr

The magneto-optical trap (MOT) is the primary tool to cool atoms. The development of this technique led to spectacular breakthroughs in experimental quantum physics, such as optical lattices, cold molecules, or Bose-Einstein condensates. But the MOT is a complex object, as spatio-temporal instabilities of this cloud are commonly observed. Several models with different approaches have been proposed to describe these dynamics, and to identify the mechanisms leading to instabilities. Unfortunately, none of these models gives a satisfying description of the observed dynamics.

Recently, it has been proposed to describe the MOT as a weakly damped plasma. Indeed, the cloud of cold atoms in a MOT is a confined dilute object with long-range interactions, as in plasmas. This model predicted the existence of instabilities above a relatively high threshold, so that instabilities should exist only in large MOTs. This seems in contradiction with the observations related in the literature. Moreover, no direct comparison with the experimental temporal regimes allowed validating this model. More recently, a more complete description was derived using the methods of waves and oscillations in plasmas, leading to interesting predictions. But as in the previous case, this study is based upon intermediate well-established results, valid only in specific cases, not corresponding in general to the experimental situations. It appears from these numerous works that a reference model for MOT atom clouds lacks. Such a model could help in determining precisely the analog! ies between MOT atom clouds and other systems, such as plasmas.

We present here such an exhaustive kinetic model for the atoms in a 1D MOT. We show that the atomic density is described by a Vlasov-Fokker-Planck equation, coupled with two simple differential equations describing the trap beam propagation. The analogy of such a system with plasmas is discussed. We show that such a trap is described by a Vlasov-Fokker-Planck equation with a second relaxation term and a source term, both originating in the bath of hot atoms of the atomic vapor. This VFP equation is coupled to a set of two differential equations describing the beam propagation in the cold atoms. This system could be considered as relatively similar to plasmas, where the role of the thermal bath is played by the trapping beams. However, it appears that the MOT differs from plasmas on two important points: the second thermal bath, formed by the hot atoms, induces new interactions as compared to plasmas; the trapping beams are not a “thermal” bath, as the atoms act on them through the absorption.