Optomechanical self-organization in cold atoms

The field of optomechanics deals with the mutual coupling of light-matter systems leading to their spontaneous spatial organization.[1] Cold and ultra-cold atoms have emerged as nice systems to study these effects, since they are highly sensitive to the dipole force exerted by a spatially-inhomogeneous light field.[1] Experiments to date have mostly been performed in optical cavities, leading to a single or a few modes for the spatial organization of the atoms. However, interesting predictions concern the multi-modes situation.[2]

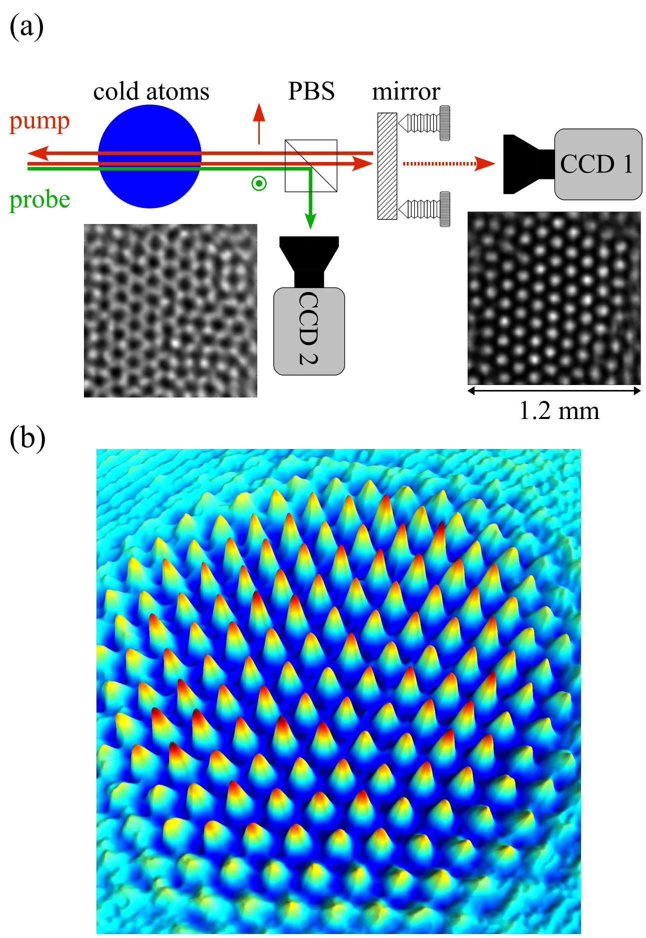

FIG. 1: (a) Experimental scheme. A pump beam passes through the cold atoms and is retro-reflected. This optical feedback causes an instability which leads to a spatial organization of both light and matter in the plane transverse to the beam axis. CCD 1 detects the formation of these patterns in the transverse intensity distribution of the transmitted pump. A probe beam of orthogonal polarization is sent through the cloud after the pump pulse and detects the transverse spatial organization of the atoms (CCD 2). (b) 3D view showing large-scale hexagonal patterns in the transverse section of the pump beam.

We used a simple single pump-beam, single-mirror feedback scheme to demonstrate the spontaneous spatial organization of a cold atomic cloud in the plane transverse to the pump axis.[3] Such a setup as been known in the past to lead to the formation of patterns in various nonlinear media including hot atomic vapors.[4] In these experiments, however, the spatial modulation only concerned the atomic internal states and not the spatial density. Because our atoms are cold and can thus easily bunch into dipole potential wells, we were able to demonstrate that the instability leads in our case to a high-contrast spatial modulation of the atomic density. Since the system is quite translation-invariant in the transverse plane and symetric about the pump axis, two continuous symetries (translation and rotation) are spontaneously broken in the process and the spatial organization can adopt many different modes.

Our study has allowed us to identify two distinct nonlinear mechanisms at work in our pattern formation experiment: the "electronic" nonlinearity (purely internal state) and the "optomechanical" one resulting from the spatial bunching of the atoms. We will continue to investigate the properties of these various instabilities. Since the pump light is detuned from the atomic transition, the atomic motion in the dipole potential landscape is essentially Hamiltonian and free from damping. The concept of the experiment could thus in principle be extended to ultra-cold atoms such as produced in a Bose-Einstein condensate, to adress the quantum physics of multi-modes systems.[2]

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