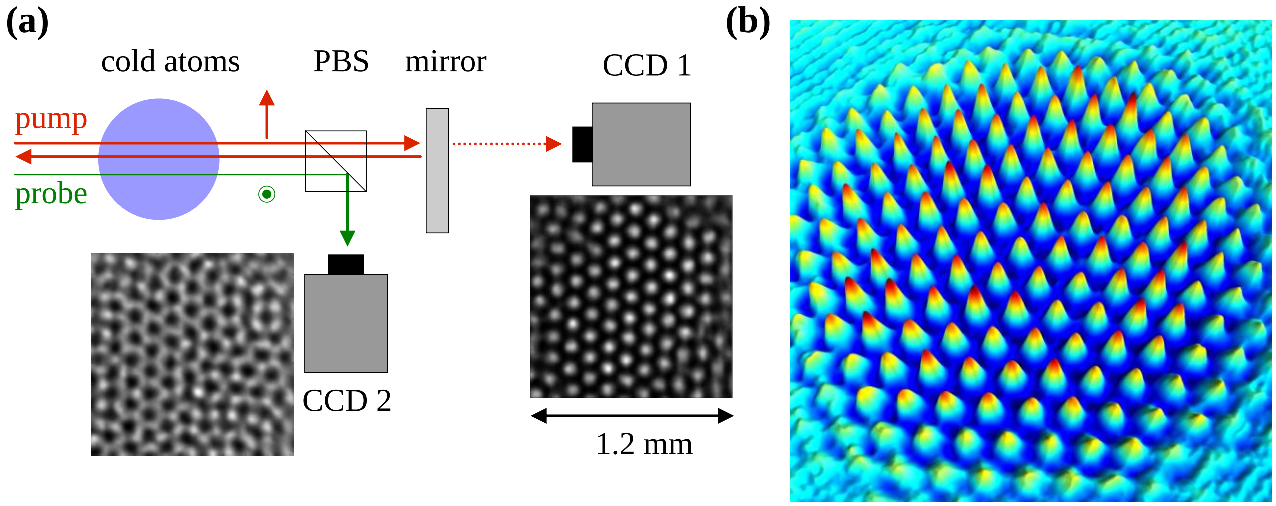
Optomechanical self-structuring of cold atoms

The field of optomechanics deals with the mutual coupling of light and matter via optical forces. This can lead to spectacular examples of spontaneous spatial organization.[1] Cold and ultra-cold atoms have emerged as useful 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 providing a single-mode for the spatial organization of the atoms. Interesting predictions, however, have been made for the multi-mode situation.[2]



(a) Experimental scheme. A pump beam tuned to the high frequency side of the D_2 line passes through a cold cloud of ^{87}Rb atoms (optical density 150, temperature 290 μK) and is then retro-reflected. CCD 1 detects the formation of transverse structures in the 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). Light and atom patterns are complementary because the dipole forces expel atoms from regions of high intensity. **(b)** 3D view of a large-scale hexagonal structure 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 has been known to lead to the formation of patterns in various nonlinear media (including hot atomic vapors[4]) where, however, the spatial modulation only affected the atomic internal states while the atomic density remained homogeneous. Cold atoms can easily bunch into potential wells created by the dipole force in a modulated light field. In our case, the instability leads to a simultaneous high-contrast spatial modulation of the atomic density. Since the system is, in principle, translation-invariant in the transverse plane and symmetric about the pump axis, two continuous symmetries (translation and rotation) are spontaneously broken in the process and the spatial organization can adopt a multitude of different modes.

Our study has allowed us to identify two distinct nonlinear mechanisms at work in our feedback experiment: the "electronic" nonlinearity (purely internal state) and the "optomechanical" one resulting from the spatial structuring 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.[5] The concept of our experiment can then be extended to ultra-cold atoms, such as those produced in a Bose-Einstein condensate, to address the quantum physics of multi-mode systems.[2]

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