Inversion symmetry breaking in cold atomic spin patterns

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Laser driven cold atoms in front of a retro-reflecting mirror exhibit self-organization above pump threshold. It was recently demonstrated how this system can be used to mimic a transverse lattice of interacting spins (see Fig. 1) [1]. The spontaneously formed lattice breaks both translational and rotational symmetries of the initial homogeneous spin state. By applying a constant longitudinal magnetic field of $|B_z| \sim 100$ mG a switching between antiferromagnetic square and ferri-magnetic hexagonal pattern ordering can be induced. We study the coupling between this magnetic field and modulations in the atomic magnetization.

The modeling of atoms as a spin-1 medium results in a set of differential equations for both the populations and coherences of the ground state magnetic sublevels. The physics of self-organization is seen more clearly by expanding the atomic density matrix via the irreducible tensor expansion. When only a longitudinal magnetic field is present, the relevant degrees of freedom are the longitudinal spin dipole and the quadrupoles representing longitudinal alignment and $|\Delta m| = 2$ ground state quantum coherence.

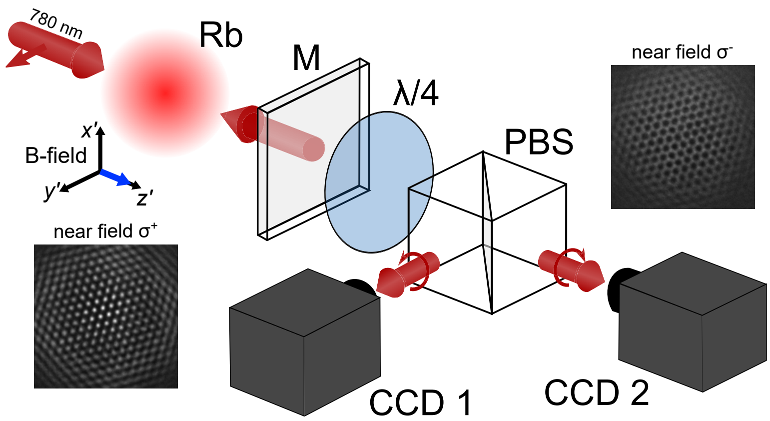

Fig. 1 Simplified schematics of the experimental setup, adapted from [1]. A linearly polarized pump beam is reflected from a feedback mirror to drive the spin self-organization in the atomic cloud. A small transmitted part of the beam is used for polarization selective NF and FF imaging. Inversion symmetry is broken by applying a small longitudinal magnetic field (B-field), resulting in formation of hexagons and honeycombs in the σ polarization channels (inset: NF data). Rb - cold cloud of ^{87}Rb, M - feedback mirror, $\lambda/4$ - quarter-wave plate, PBS - polarizing beam splitter cube, CCD - charge-coupled device camera.

Our experimentally measured variation of pattern thresholds and symmetries with B_z is compared to the results of both numerical calculations in the full model and analytical calculations in a reduced model allowing for perturbations only in the spin dipole [2]. The reduced model shows that inversion symmetry of the system is broken at small $|B_z|$ by nonlinear Faraday rotation caused by coupling of the homogeneous parts of light induced quantum coherence and spin dipole. A complex Ginzburg-Landau equation governing the wave mixing of spin roll states is derived. At large $|B_z|$ the behavior cannot be accounted for by the reduced model, leading to the conclusion that perturbations in magnetic quadrupoles govern the pattern behavior in this regime.

Understanding of spontaneous light-mediated atomic ordering has potential relevance for future quantum technologies. Our study could provide a basis for further research on instabilities in driven multilevel systems with feedback, which have in the past been largely unexplored due to their complexity.

References

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