Implementation of a Dipolar Quantum Gas Microscope

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In the last decade, the emergence of quantum gas microscopes has propelled investigations of strongly correlated quantum phases [1]. Single-atom resolution can be achieved using high–numerical-aperture objectives, which entails an extremely low depth of focus. In our quantum gas microscope for the highly magnetic dysprosium atoms, featuring a 0.9 NA objective [2], we implemented a tunable optical lattice to precisely control the position and spatial extent of the atomic cloud so that it coincides with the 300 nm focal plane of the objective. I will present the optical system we designed to create this tunable lattice, achieving substantially reduced aberrations compared with commercial alternatives. Through a detailed analytical study of the ground-state evolution using the Lie-algebraic Wei-Norman method, we investigated the impact of residual aberrations on the atomic gas. Additionally, we studied the dynamics of a thermal atomic gas in a shifted optical dipole trap by numerically solving the Boltzmann equation. These results will enable the production of very low-entropy states in optical lattices and the measurement of the exact site occupation number of dipolar atoms, paving the way for the experimental observation of exotic magnetic phases [3].

[1] M. Greiner, W. S. Bakr, J. I. Gilligan, *et al.*, *A quantum gas microscope for detecting single atoms in a Hubbard-regime optical lattice*, Nature **462**, 74–77 (2009).
[2] M. Sohmen, M. J. Mark, M. Greiner, and F. Ferlaino, *A ship-in-a-bottle quantum gas microscope setup for magnetic mixtures*, SciPost Physics **15**, 182 (2023).
[3] D. Rossini and R. Fazio, *Phase diagram of the extended Bose–Hubbard model*, IOPscience (2012).

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