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PhD THESIS DEFENSE: A strontium quantum-gas microscope

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10:00
ICFO Auditorium

The development of quantum-gas microscopes has revolutionized the field of quantum simulation with ultracold atoms. More specifically, their ability of direct observation and manipulation of degenerate quantum gases in optical lattices on a single particle level has brought novel ways of probing and engineering quantum degenerate many-body systems. So far, most of these setups have focused on alkali atoms. Combining quantum-gas microscopy with the properties of alkaline-earth atoms such as strontium gives rise to exciting research directions. In this thesis, we report on the design and construction of a strontium quantum-gas microscope. The findings in this thesis can be divided into three parts.
In the first part, we focus on the accumulation of atoms in the science cell and develop a scheme to enhance the atom number in magneto-optical traps of strontium atoms operating

on the 461-nm transition. This scheme resonantly populates a short-lived reservoir state, partially shielding the atomic cloud from losses in the cooling cycle. We demonstrate a factor of 2 enhancement in the atom number for the bosonic isotopes Sr-88 and Sr-84, and the fermionic isotope Sr-87, showing the efficient capture of these isotopes in our experiment. Our scheme can be readily implemented in the majority of strontium experiments, given that the shielding transition at 689 nm is commonly used for further cooling. In our case, the shielding scheme facilitates the generation of Bose-Einstein condensates.
The second part of the thesis reports on the generation of degenerate quantum gases of Sr-84 with up to 200000 atoms. After summarizing the required cooling steps, we study the formation of Bose-Einstein condensates during evaporative cooling in our experiment. Analyzing the evolution of the horizontal and vertical size of our quantum-degenerate clouds in free fall leads to the characteristic asymmetric expansion, which we compare to theory for our experimental parameters. We also show the generation of smaller Bose-Einstein condensates of less than 20000 atoms with the help of a light-sheet potential. With this highly-anisotropic confinement we can consider our Bose-Einstein condensates two-dimensional for atom numbers of the order of 1000.
In the third part we demonstrate site-resolved imaging of a Sr-84 bosonic quantum gas in a Hubbard-regime optical lattice potential. We confine the quantum gas by a two-dimensional optical lattice and the aforementioned light-sheet potential, both operating at strontium's clock-magic wavelength. A high-NA imaging objective enables single-atom and single-site resolved fluorescence imaging by scattering photons on strontium's broad 461-nm transition, while performing efficient attractive Sisyphus cooling of the atoms on a narrower transition at 689 nm. We reconstruct the atomic occupation of the lattice sites from the fluorescence images, obtaining imaging fidelities above 94%. Finally, we realize a Sr-84 superfluid in the Bose-Hubbard regime and observe its characteristic interference pattern after free expansion in the light sheet with single-atom resolution.
Our strontium quantum-gas microscope provides a new platform to study dissipative Hubbard models and cooperative effects in atom-light interaction at the microscopic level. Moreover, the ability to capture also the fermionic isotope Sr-87 paves the way to generate degenerate Fermi gases with SU(N) symmetry and study SU(N) quantum magnetism.

Monday April 29, 10:00 h. ICFO Auditorium
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