Exploring light-induced correlations in disordered atomic ensembles in optical tweezers

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Introducing optical tweezers in cold atoms experiments has allowed in the last few years for unprecedented control capabilities in many-body systems preparation and manipulation, thanks to the high degree of control of individual atom position and state. However, understanding the physics of atomic ensembles confined in such tight traps remains challenging, particularly in the presence of resonant light. While some studies have been performed in traps with sizes of a few micrometers [1, 2], the sub-micrometer regime is still poorly explored. Strong confinement allows one to reach sub-wavelength mean interatomic distances, even with non-degenerate gases, thereby allowing to uncover collective effects even with a small number of atoms. In this talk, I present our results on the effects of near-resonant light in a multiply loaded optical tweezer. In particular, I show how the recently introduced flash imaging protocol allows us to determine the number of atoms in a tweezer[3]. Using this technique, we first studied the dynamics of light-assisted collisions, a fundamental tool for single-atom preparation in optical tweezers. Moreover, the high-density regime in optical tweezers allowed us to observe signatures of light-induced correlations among atoms, even when only a few atoms are loaded in a single trap. Exploring these systems can help to understand how light correlates disordered atomic ensembles and how the atomic state evolves, helping to uncover the mechanisms governing the transition from superradiant to subradiant states.

[1] G. Ferioli *et al.*, *Phys. Rev. X* **11** 021031 (2021).
[2] G. Ferioli *et al.*, *Nature Phys.* **19** 1345-1349 (2023).

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