Ultrafast Meets Ultracold: Optical 2D Coherent Spectroscopy of Cold Atoms

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Ultrafast femtosecond lasers are rarely used to study ultracold atoms since they are intrinsically incompatible in their characteristic time scales. However, we found optical 2D coherent spectroscopy (2DCS) enabled by femtosecond lasers a powerful tool for studying many-body physics in atomic ensembles including cold atoms.

Many-body interactions and correlations in atoms are fundamentally important for many systems such as cold atoms/molecules, improving the precision of optical atomic clocks, and enabling many-body quantum simulation in atom-based quantum simulators. Double-quantum 2DCS provides sensitive and background-free detection of weak dipole-dipole interactions, as demonstrated in both potassium (K) and rubidium (Rb) atomic vapors [1-2]. The technique can be extended to multi-quantum 2DCS which can probe multi-atom correlated states (Dicke states) with up to eight atoms in a K vapor [4-5]. We have also observed collective resonances of higher excited states (D state) in addition to P state [5].

However, atomic vapors at room or higher temperatures pose extra challenges in the quantitative and deterministic study of many-body interactions and correlations due to the presence of thermal motion. Compared to thermalized atom vapors, cold atoms provide a well-controlled environment. With the recent advance in cooling and trapping an array of single atoms by using optical tweezers, it is possible to study many-body physics in an atom array with a deterministic atom number and interatomic spacing. Our previous 2DCS measurements in a dilute atomic vapor have shown that 2DCS has sufficient sensitivity for a typical cold atom density [6] and even a single atom. Recently, we have implemented [7] optical 2DCS on Rb cold atoms at about 200 μK in a magneto-optical trap (MOT). This was accomplished by combining a collinear 2DCS setup with an MOT. We first performed one-dimensional (1D) pump-probe and transient four-wave mixing (FWM) spectroscopy. We then demonstrated optical 2DCS and obtained 2D spectra of cold atoms. This demonstration is an important first step towards the goal of using optical 2DCS to study many-body physics in cold atoms and ultimately in atom arrays trapped by optical tweezers.

References

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