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Witnessing the formation and relaxation of dressed quasi-particles in a strongly correlated electron system

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The non-equilibrium approach to correlated electron systems is often based on the paradigm that different degrees of freedom interact on different timescales. Photo-excitation is treated as an impulsive injection of electronic energy that is transferred to other degrees of freedom only at later times. By studying the ultrafast dynamics of quasi-particles in a strongly correlated charge-transfer insulator ($La_2CuO_{4+\delta}$), we show that the interaction between electrons and bosons manifests itself directly in the photo-excitation processes of a correlated material. We reveal that sub-gap excitation pilots the formation of itinerant quasi-particles, dressed by an ultrafast reaction of the bosonic field. The exact diagonalization of the Hubbard–Holstein model[1] explains the different response measured for above-gap and sub-gap excitations (Figure 1 and 2). In particular, a perturbation with sub-gap photon energy drives a non-thermal tendency to create strongly dressed quasi-particles. This discloses several possible scenarios where coherent electromagnetic fields can be used to manipulate quantum coherent phases of matter[2].

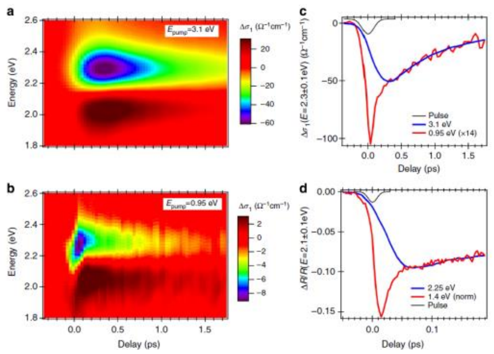

Figure 1 | Time-domain evolution of optical conductivity. The measurements performed at 130 K are reported as a function of probe energy for pump energy (a) larger (3.1 eV with 0.04 eV bandwidth) and (b) smaller (0.95 eV with 0.04 eV bandwidth) than Δ. (c) The transient optical conductivity at E_{probe} at 2.3 eV for both pump energies is shown (3.1 eV in blue, 0.95 eV in red). The response for sub-gap excitation is multiplied by the ratio of the absorbed energy densities. The black curve depicts the 3.1 eV pump autocorrelation. (d) Normalized pump–probe reflectivity measurements performed at room temperature with 10 fs pulses (in black the pulse duration).

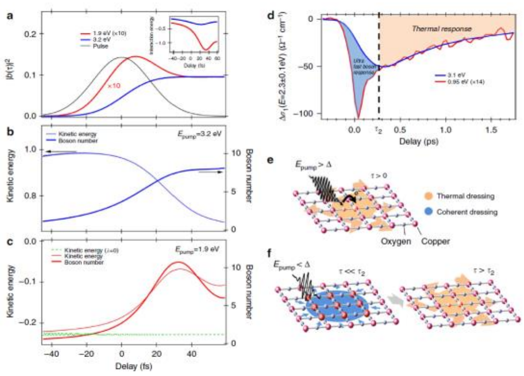

Figure 2 | Hubbard–Holstein calculations. (a) The weight, $|b(t)|^2$ of the photo-excited component of the wave function as a function of pump–probe delay for excitations below (red) and above (blue) Δ. In the inset of a, the interaction energy in eV is shown. The average number of bosons (thick line) and the electron kinetic energy in eV (thin line) for the two excitation wavelengths are reported in b and c. In a, b and c, the differences between the pump-perturbed quantities and the ground state ones are shown. In e and f, cartoons of the physical mechanism are sketched. $E_{pump}>\Delta$ (e): thermal dressing scenario; $E_{pump}<\Delta$ (f), a ‘coherent dressing’ mechanism is in action at very short time delays.

[1]De Filippis, G. et al., Phys.Rev. Lett. 109, 176402 (2012); [2] Fausti, D. et al., Science 331, 189–191 (2011).