ESRF	**Experiment title:** Study of the phonon anomalies in the cuprate superconductor LSCO	**Experiment number**: HC3108
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We studied the anomalous phonon behavior around the charge-density-wave (CDW) vector q_{CDW} ~ 0.235 rlu in $La_{2-x}Sr_xCuO_4$ (LSCO) x=0.125 at a number of temperatures. The phonon anomalies are regarded as significant anomalous dispersion and linewidth broadening of the Cu-O bond-stretching phonons, consistent with strong electron-phonon coupling [1]. It appears that these anomalies are related to dynamic charge instabilities within the quintessential CuO_2 planes, i.e., charge-spin 'stripe' or CDW correlations. The recent discovery of CDW correlations in numerous cuprates via hard X-ray and soft resonant X-ray scattering constitutes a significant development in this regard, as it demonstrates a universal tendency toward some form of charge order [2-4]. Our experiment aimed to demonstrate the temperature dependence of the phonon anomalies and to build a clear connection between phonon anomalies and CDW correlations in this material.

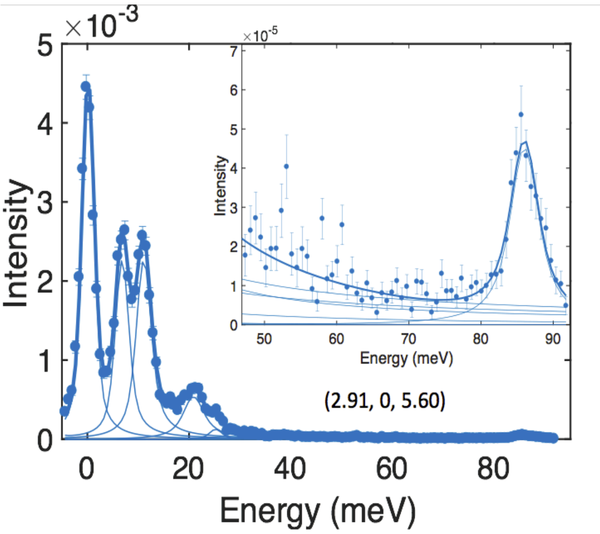

Figure 1 IXS spectrum around Q = (2.91, 0, 5.6) from -5 meV to 90 meV at 20K. The thick solid line is the fit to Lorentzian lineshape convoluted with resolution function. The thin solid lines indicate elastic and phonon peaks respectively. Inset: The Cu-O bond stretching mode that we studied in this experiment.

We studied 12.5%-doped LSCO, where the charge-order phenomenon measured with hard X-rays is particularly robust [4]. The single crystal with area 1 x 1 mm^2 had its a-b plane parallel to the surface, and was polished down to 30 μm to maximize the transmission intensity. Energy transfer spectra in the range -5 to 90 meV were measured simultaneously with 8 analyzers. The sample was aligned with the main analyzer around q_{CDW} ~ (0.235,0,0.5) and other analyzers in the H-L plane **Q** = (H=3-q,K=0,L=5.5±0.2). We managed to observe the Cu-O bond stretching mode by choosing appropriate Brillouin zone (3-q,0,5.5±0.2) and relatively long counting time (about 24 hours for the whole spectrum per temperature). We measured at three different temperatures: 20K, 150K and 300K (20K < T_c < T_{CDW} < 150K < T_s < 300K < T^*, where T_c is the superconducting transition temperature, T_{CDW} is the onset temperature of CDW correlations, T_s is the structure transition temperature, and T^* is the pseudogap temperature). Figure 1 shows a typical IXS spectrum around (2.91,0,5.6) at 20K. Although phonon peaks are not well separated in the intermediate energy region (30 to 60 meV), the whole spectrum can be fit using one elastic peak and 4-6 phonon peaks.

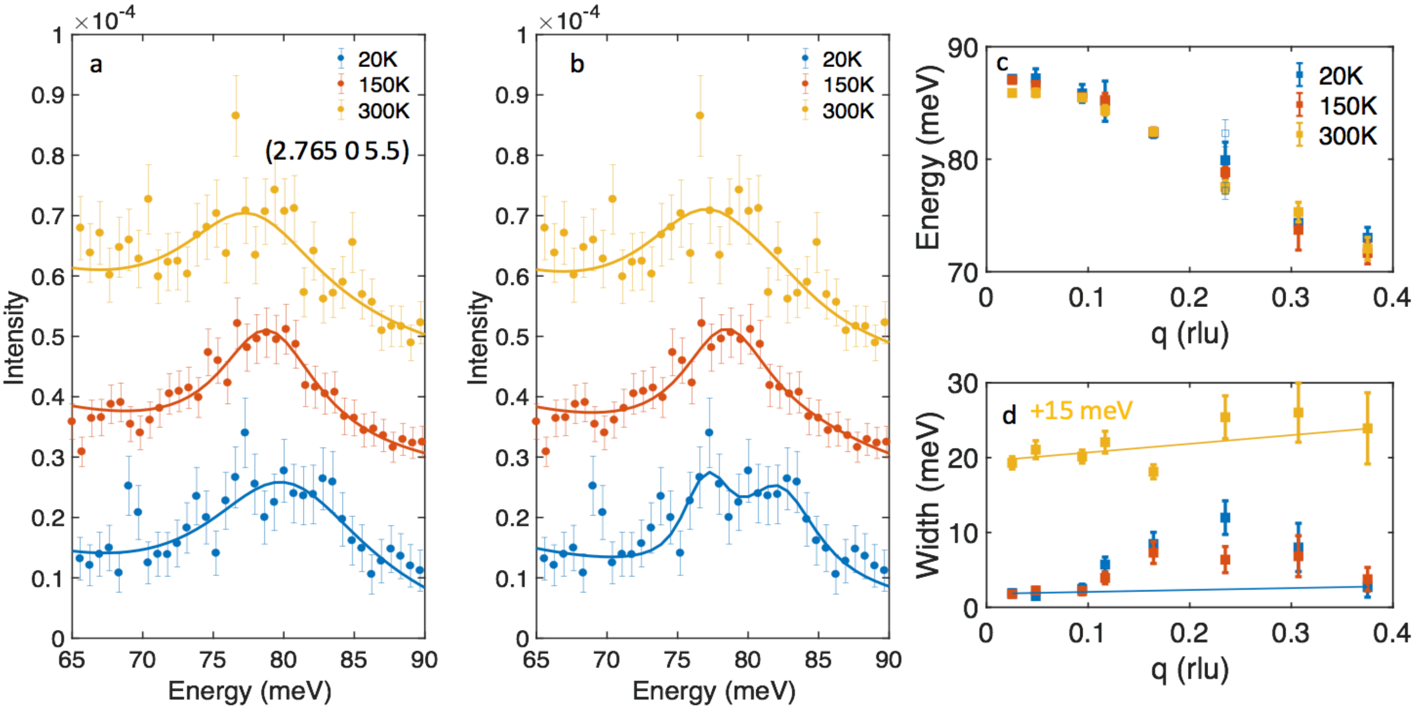

Figure 2 Temperature dependence of bond-stretching phonones. IXS specta around Q_{CDW} = (2.765, 0, 5.5) with fits to (a) single mode and (b) double modes. (c) Dispersion at different temperatures. Filled squares represent energies from the fits with one mode and open squares represent fits with two modes. (d) Momentum dependence of deconconvoluted phonon linewidth obtained from single mode fits. Solid lines indicate baseline width that smoothly increase towards the zone boundary.

The temperature dependence of phonon anomaly is shown in Figure 2. As indicated in ref. [5], the low temperature (20 K) data can be either analyzed by a degenerate phonon mode with anomalous linewidth broadening or by two separate phonon modes with a sharp downturn in the dispersion. We note that this effect is not due to cell doubling as a result of the structure transition, since the effect is reduced at 150 K, which is still well below T_s (LSCO undergoes a structure transition from high-temperature-tetragonal (HTT) to low-temperature-orthorhombic phase (LTO) at moderate temperatures - for x=0.125, T_s ~ 240K). Alternatively, the translational symmetry breaking caused by CDW correlations may be the origin of phonon anomalies.

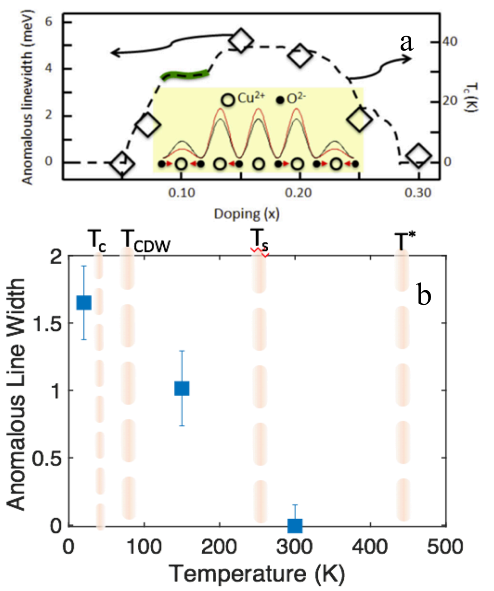

Figure 3 Doping and Temperature dependence of anomalosu linewidth in LSCO. a: figure from [6], average linewidths between q = 0.1 and q=0.37 after subtracting baseline linewidths. b: integrated linewidth in the same range after baseline subraction.

Propr work showed that the doping dependence of the amplitude of the phonon anomaly follows the superconducting dome (Figure 3a [6]). As shown in Figure 3b, we obtained crucial information on the temperature dependence by integrating the excess linewidth above the estimated baseline (see Figure 2d). The effect is most robust at low temperature, reduced (but still visible) at 150K, and finally significantly weakened or absent at 300K. The fact that the phonon anomaly still occurs above T_{CDW} (~80K [4]) indicates that dynamic charge fluctuations, which are hard to probe via energy-integrating diffraction techniqiues, indeed exists above T_{CDW}. However, we were only able to measure three temperatures during this experiment. In order to obtain a conclusive result regarding how phonon anomalies are connected with other properties in the doping-temperature phase diagram, we need to extend our study to other temperatures and doping levels.

References

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