ESRF	**Experiment title:** Inelastic X-ray scattering study of the doping and temperature dependence of electron-phonon anomalies in $Nd_{2-x}Ce_xCuO_4$	**Experiment number**: HC3124
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The 2012 discovery with synchrotron X-rays of charge-density-wave (CDW) correlations in competition with superconductivity in hole-doped $YB_2Cu_3O_{6+\delta}$ (YBCO) has attracted much attention [1,2]. Subsequent X-ray experiments demonstrated the existence of CDW correlations in other hole-doped cuprates [3-5] and in the archetypal electron-doped cuprate $Nd_{2-x}Ce_xCuO_4$ (NCCO) [6,7]. Charge correlations have long been argued to manifest themselves as an anomalous lineshape and dispersion of the longitudinal Cu-O bond-stretching phonon mode in the hole-doped cuprates [8,9]. In pioneering inelastic X-ray scattering (IXS) work at the ESRF, M. d'Astuto *et al.* revealed similar anomalous phonon behavior in nearly-optimally-doped $Nd_{2-x}Ce_xCuO_4$ (NCCO) [10]. The two-dimensional wave vector (H,K) ≈ (0.2,0) where the anomalous phonon softening was found is consistent with the recently observed CDW wave vector at the same doping level [7]. Our experiment aimed to extend the previous work of ref. [10] to a wider doping and temperature range, and to search for a connection between CDW correlations and phonon anomalies in NCCO.

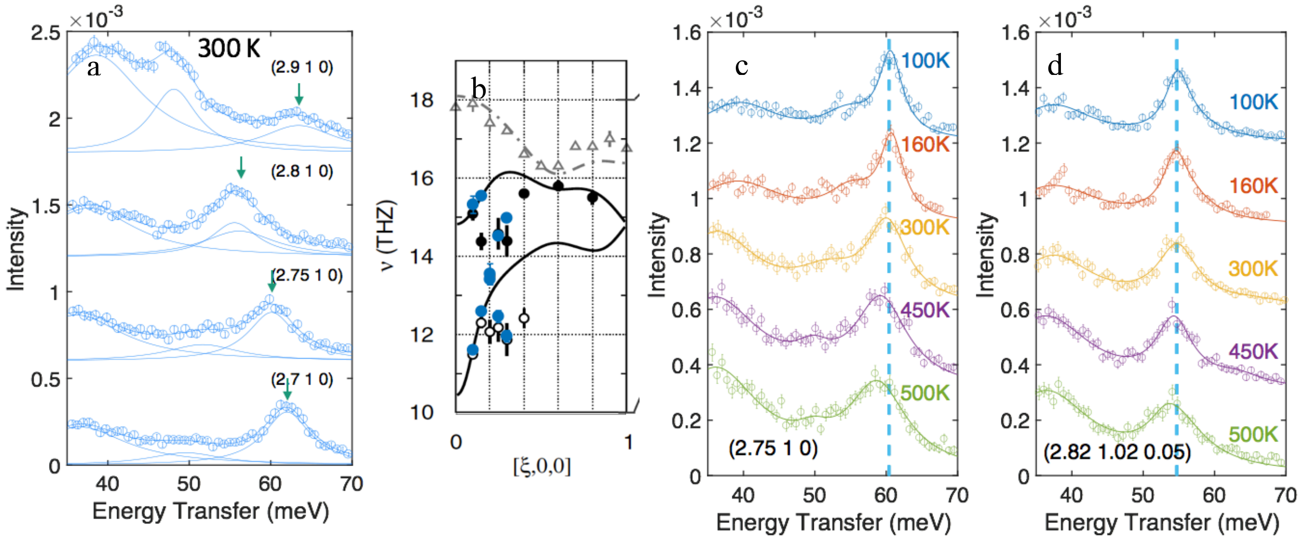

Figure1 Momentum and temperature dependence of phonons in nearly optimally doped NCCO (x=0.145). (a) IXS spectra of the high energy phonon modes at different momenta. Three phonon modes can be fit in the range 35 to 70meV. The bond-streching phonons are marked by blue arows. (b) Dispersion of the two highest-energy modes at 300K (blue circles) are compared with the 20K prior data from ref. [10]. Temperaure dependence of the phonon peaks around (c) the CDW wavevector $\mathbf{Q}_{CDW}$ = (2.75 1 0) and (d) phonon anomaly wavevector $\mathbf{Q}_{ph}$ = (2.82 1.02 0.05).

The samples investigated in the present study were pieces of the same crystals used for the recent resonant X-ray measurement of CDW correlations [7], with a-b planes parallel to a large 1 mm x 1mm surface, and polished down to 30 μm to maximize the transmission intensity. Energy transfer spectra in the range -5 to 90 meV were measured simultaneously via 8 analyzers, with the main analyzer set around $\mathbf{Q}_{CDW}$. In order to clearly observe the high-energy longitudinal phonon modes, we performed the measurements along $\mathbf{Q}$ = (3-q, 1, 0) with relatively long counting time.

Figure 1 shows the phonon anomaly for a nearly optimally-doped sample (x = 0.145). The anomalous softening at $q_{ph} \sim 0.2$ of the Cu-O bond stretching mode (Figure 1a, marked by blue arrows) reported at 20 K in ref. [10] is well reproduced at 300 K (Figure 1b). In order to search for a connection between the CDW and the phonon anomaly, we performed a comprehensive study of the temperature dependence of the phonon modes around $q_{CDW} \sim 0.25$ and $q_{ph} \sim 0.2$ (Figure 1 c and d). As for YBCO [11], if the phonon anomaly is associated with the CDW, one would expect that the soft phonon would gradually harden across T_{CDW}. However, as shown in Figure 1, the phonon energy remains unchanged between 100 K to 500 K. Given the pronounced CDW peak at the highest temperature (380 K) measured by resonant elastic X-ray scattering (REXS), it is possible that CDW correlations in NCCO are still robust even at 500 K.

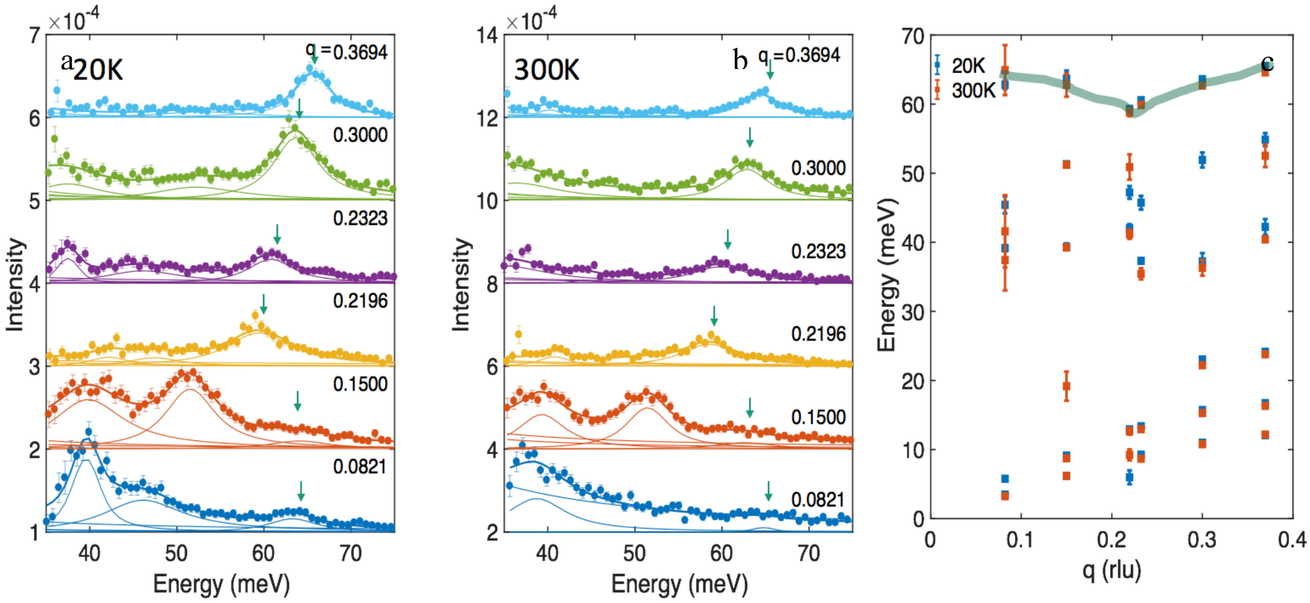

Figure 2. Momentum and temperature dependence of phonons in underdoped NCCO (x=0.078). IXS spectra of three high energy phonon modes at (a) 20 K and (b) 300 K. The arows indicate the bond-stretching phonon modes. (c) Phonon dispersion at 20 K and 300 K. Solid line is guide to the eye.

We then decided to switch to a lightly-doped non-superconducting sample (x=0.078), for which only weak CDW peaks were detected at low temperatures, and no CDW correlations were observed at room temperature [7]. Interestingly, the phonon softening occurs in this doping as well and even persists at 300 K. Figure 2c shows that the phonon disperations at 20 K and 300 K are nearly indistinguishable. This indicates that the phonon anomaly is not directly tied to CDW correlations in NCCO.

In summary, we performed an IXS study of bond-stretching phonons in two different samples of the archetypal electron-doped cuprate NCCO, for which distinct temperature-dependent CDW behaviors had been detected. Although both samples show phonon softening around $q_{ph} \sim 0.2$, close to the CDW wave vector $q_{CDW} \sim 0.25$, the temperaure-insensitive behavior of the phonon anomaly indicate that this anomaly is not closely related to CDW correlations. The fact that $q_{ph} \approx q_{CDW}$ is, most probably, a mere coincidence. An ab-initio calculation will need to be performed in order to understand if the observed behavior is in fact anomalous, or if it is merely a regular crossing between two phonon branches.

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