ESRF	**Experiment title:** Low-energy excitations of the CDW state in electron doped cuprates.	**Experiment number**: HC2386
Beamline: ID32	**Date of experiment**: from: 08 June 2016 to: 14 June 2016	**Date of report**: Feb 27, 2016
Shifts: 18	**Local contact(s)**: Nick Brookes	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Eduardo H. da Silva Neto* - University of California, Davis.

Andrea Damascelli – University of British Columbia

Matteo Minola*, Martin Bluschke*, Hakuto Suzuki*, Bernhard Keimer – Max Planck Institute FKF

Biqiong Yu, Martin Greven – University of Minnesota

Wojchech Tabis* – LNCMI Toulouse

Mathieu Le Tacon – Karlruhe Institute of Technology

Report:

The goal of the experiment was to perform Cu-L_3 Resonant Inelastic X-ray Scattering (RIXS) measurements of the charge density wave (CDW) in the electron-doped cuprate $Nd_{2-x}Ce_xCuO_4$ (NCCO). The primary question regarded the nature of the CDW in electron-doped cuprates: is the CDW purely elastic or does it have inelastic spectral features? We measured two NCCO samples, x = 0.106, x = 0.145, and constructed energy-momentum RIXS intensity maps focusing around the CDW momentum transfer, Q_{CDW}. The spectrometer was set to its highest back scattering geometry (2θ=149.5°). Different values of the in-plane momentum transfer along the Cu-O bond diretion (H in reciprocal lattice units) were accessed by rotating the sample about an axis perpendicular to the scattering plane, *i.e.* to different θ angles (rocking curves). At each θ we measured the spectrum for several minutes, with the beamline and spectrometer conditions optimized for an energy resolution of ~ 60 meV. Prior to the acquisition of a set of spectra on the sample, we measured the spectrum on a thin layer of silver paint (located on the sample surface) to obtain the pixel location of the zero energy loss on the CCD camera detector.

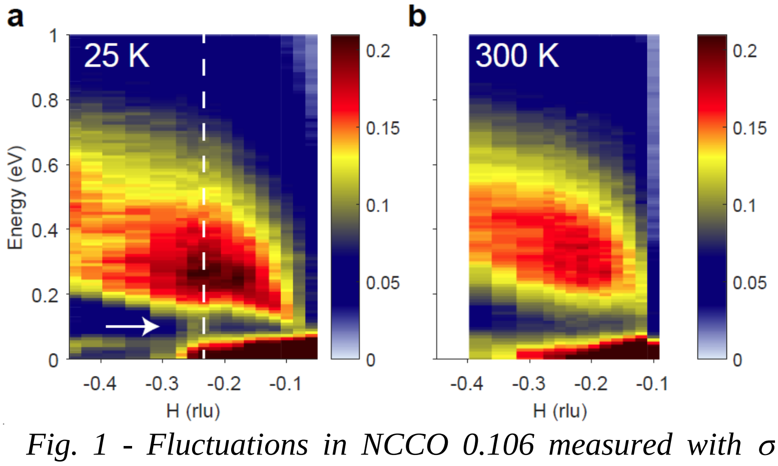

Fig. 1 - Fluctuations in NCCO 0.106 measured with σ scattering. Dashed line indicates Q_{CDW}.

Figure 1a shows the detailed energy-momentum structure of the low-energy collective excitations of an underdoped non-superconducting NCCO sample (x = 0.106) at 25 K. With this RIXS geometry (forward scattering, H<0, and incoming sigma polarization), the broad dispersive modes in the mid-infra-red (150 < E < 900 meV, MIR) region, usually associated with magnetic (paramagnon) fluctuations [1], show a clear coupling to the CDW. This is manifest in the data of Fig.1 as a dispersion anomaly near Q_{CDW} and as a distinct inelastic component (60 < E < 150 meV), marked by the white arrow in

Fig. 1a. Comparing this low-temperature measurement to its counterpart at 300K (Fig. 1b) we find that these two inelastic features are mostly suppressed at high temperatures, as expected. Furthermore, the temperature dependence also shows a build-up of spectral weight of the inelastic MIR modes at Q_{CDW}. A similar inelastic structure near the Q_{CDW} structure is also observed in measurements of the same sample for H > 0, and it is confirmed in measurements performed at 25K on a superconducting NCCO sample (x = 0.145) for σ- and π-geometry (not shown).

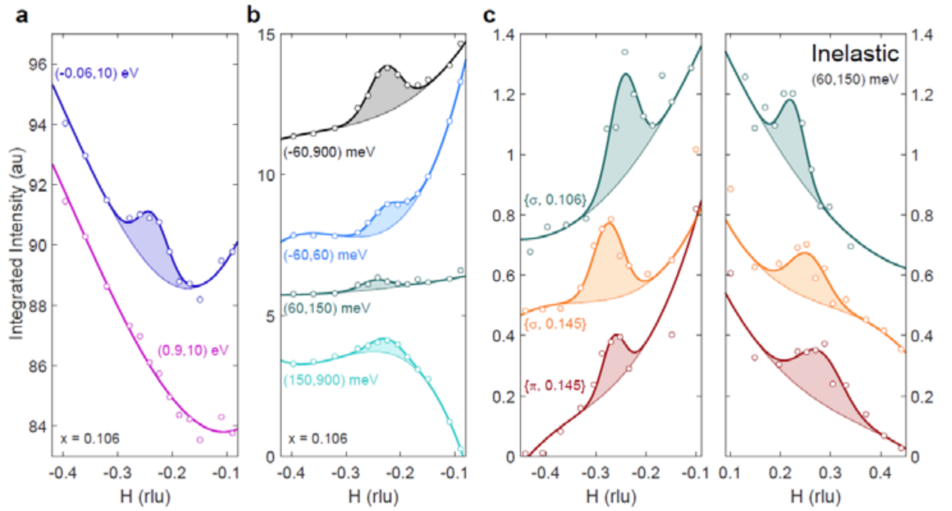

Fig. 2 - RIXS signal integrated over different energy ranges following the description in the text. The data are displayed by open circles, and the thick lines are a fit using a polynomial plus a Gaussian .function.

To decompose the different elastic and inelastic contributions at Q_{CDW}, we separate the RIXS spectrum into different energy regions and we build energy-integrated H distribution curves for each of them. We emphasize that in the following analysis we integrated very specific energy regions that we determined from the inelastic spectrum. **This analysis could not be done with data from a REXS experiment.** Figure 2a shows the signal integrated over all measurable energies (blue curve). The ratio of the CDW peak to the total signal (~ 1%), as well as the overall shape of the fluorescence background, greatly resemble previous REXS measurements [2]. However, the momentum distribution curve obtained integrating the RIXS spectra in the 0.9 eV to 10 eV range shows the absence of any CDW peak in that energy region (Fig. 2a, magenta). In Fig. 2b we decompose the CDW signal (present for -60 < E < 900 meV) into quasi-elastic (-60 < E < 60 meV), low-energy inelastic (60 < E < 150 meV), and MIR (150 < E < 900 meV) contributions. The most important outcome of this decomposition is that half of the CDW signal comes from **inelastic** excitations, therefore achieving the primary goal of the experiment. The inelastic component of the CDW (Fig. 2c) is confirmed by measurements of NCCO samples with two different dopings (0.106 and 0.145) and four scattering geometries (σ, π polarizations for ±H). Finally, our analysis also shows a non-trivial temperature dependence of the quasi-elastic and inelastic CDW signals (Fig. 3). In particular, note that while the quasi-elastic CDW is completely suppressed at 300K, the MIR component still shows a distinct maximum near Q_{CDW}.

We conclude by mentioning that further temperature-dependent data may be required to clarify this behavior whereas fully-polarimetric measurements, which resolve the polarization of the scattered photons, will be needed to understand the nature of the CDW-related MIR signal (charge or spin excitations).

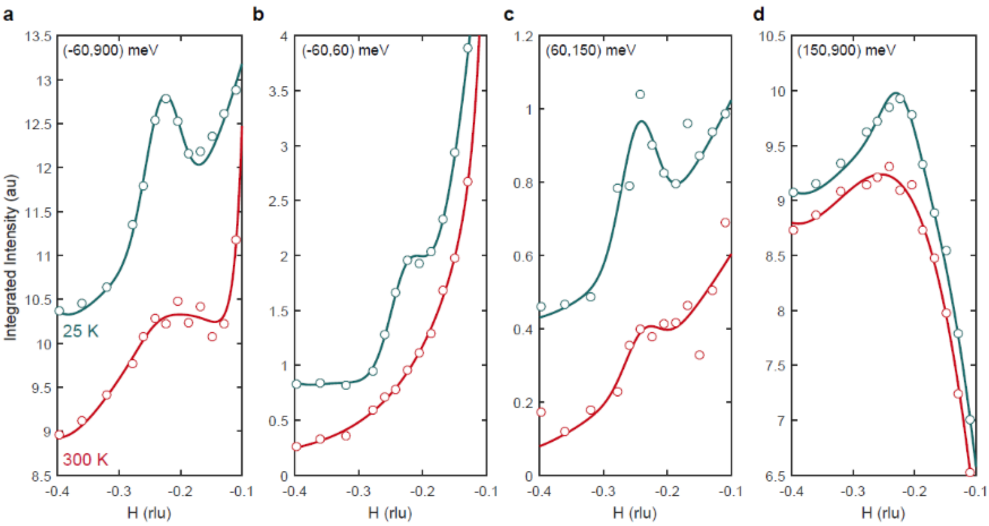

Fig. 3 - Energy-integrated RIXS spectrum for 25K and 300K. All data taken on NCCO with x = 0.106 and with σ-polarized incoming photons. Data is represented by open circles, and the lines are a fit using a polynomial function plus a Gaussian function.

[1] L. Braicovich, et al. PRL 104, 077002 (2010) and M. Le Tacon, et al. Nat. Phys. 7, 725 (2011).
[2] E. H. da Silva Neto, et al. Science **347**, 282 (2015) and Sci. Adv. **2** (8), e1600782 (2016).