EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

ESRF

# Experiment Report Form

**The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF**.

Once completed, the report should be submitted electronically to the User Office via the User Portal:
*https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do*

## Deadlines for submission of Experimental Reports

Experimental reports must be submitted within the period of 3 months after the end of the experiment.

### Experiment Report supporting a new proposal ("relevant report")

If you are submitting a proposal for a new project, or to continue a project for which you have previously been allocated beam time, you must submit a report on each of your previous measurement(s):

- even on those carried out close to the proposal submission deadline (it can be a *"preliminary report")*,
- even for experiments whose scientific area is different form the scientific area of the new proposal,
- carried out on CRG beamlines.

You must then register the report(s) as "relevant report(s)" in the new application form for beam time.

## Deadlines for submitting a report supporting a new proposal

- 1st March Proposal Round **- 5th March**
- 10th September Proposal Round **- 13th September**

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

### Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

### Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

### Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report in English.
- include the experiment number to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

**ESRF**

**Experiment title:**
Disentangling the orbital symmetry of a new charge order in overdoped $(Bi,Pb)_2Sr_2CuO_{6+delta}$ superconductor

**Experiment number:** HC3314

**Beamline:** ID32

**Date of experiment:** from: 20 September 2017 to: 24 September 2017

**Date of report:** March 2, 2020

**Shifts:** 12

**Local contact(s):** Davide Betto

*Received at ESRF:*


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**Report:**

Charge-density-waves (CDWs) in underdoped cuprates are considered to be an intrinsic competitor to superconductivity. Its origin has been hotly debated and was suggested to connect with a quantum critical point around optimal doping, beyond which CDWs seem to disappear. During our last beamtime (LTP HC886, October 2016), we have observed by Cu-$L_3$ RIXS a strong charge order signal at $Q_{//}$~0.14 rlu in overdoped Bi2201, as shown in Fig. 1 (b) for OD17K ($T_c$=17K, $p$~0.2). Compared to the short-ranged CDW in the underdoped region (~6 lattice units) [1,2], this new CDW is very long-ranged, with coherence length ~50 lattice units. This raises several important questions: What is the origin of this long-ranged CDW in the overdoped region? What is its relation with the CDW in the underdoped region? This finding urgently invites further investigation on its origin. Moreover, the intriguing result of OD17K, obtained at two temperatures only (20 K and 100K), needs to be completed by a thorough *T*-dependent study. By exploiting the unique RIXS instrumentation at ID32, we propose to complete the *T*-dependent measurements, which were only partially done last time, to determine the onset temperature $T_{CDW}$, if anyway reachable. These results can provide insights into the origin and the microscopic description of charge order in the overdoped cuprates, and its interplay with superconductivity.

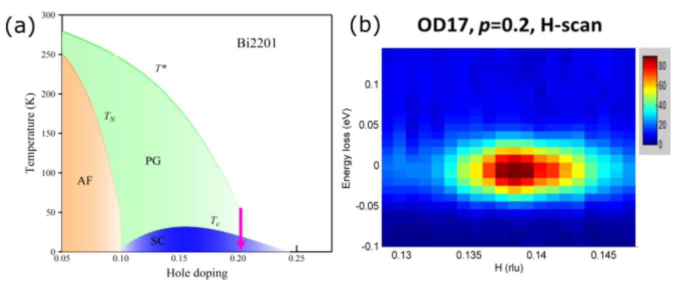


Figure 1: (a) Phase diagram of Bi2201. (b) The CDW peak in overdoped Bi2201 ($T_c$=17K, $p$=0.2) along *H* direction, measured at Cu-$L_3$ edge with σ-polarization at 20K.

In this experiment HC3314 we performed further measurements in both underdoped and overdoped Bi2201 to understand the origin of CDW. We have investigated the *T*-dependence of CDW from base temperature 20K to 300K. We found CDW peak intensity is almost independent of temperature.

As shown in Figure 2a, we found the value of the charge order wavevector decreases with doping, in line with the extrapolation of the trend previously observed in underdoped Bi2201 [1,2]. Figure 2b shows the extended phase diagram of charge order in Bi2201. These results have been pulished in Nature Materials 17, 697-702 (2018).

To understand the CDW in underdoped and overdoped regions, we consider the 'frustrated phase separation' approach, previously proposed for the underdoped regime, in which some generic (phononic and/or magnetic) non-critical effective attraction drives the system towards electronic phase separation. As the segregation of charges over large regions is prevented by the electron-electron Coulomb repulsion, the system finds a compromise by forming a CO state where charge is segregated on a short length scale while large-scale charge neutrality is maintained [3].

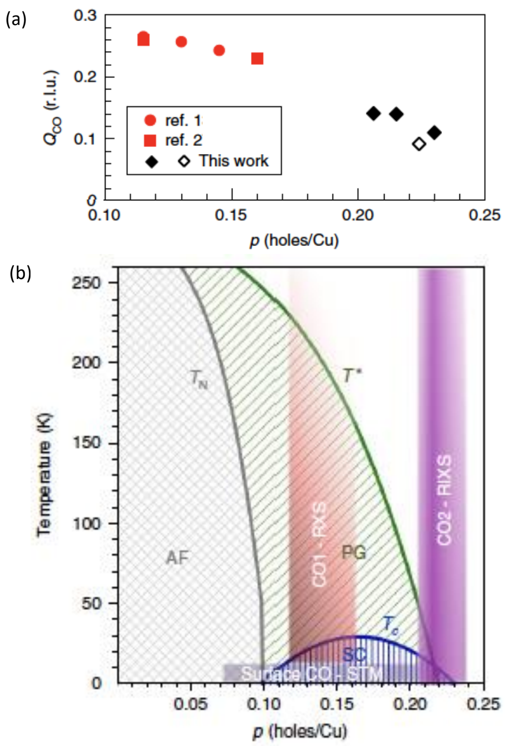


Figure 2: (a). Doping dependence of the CO wavevector [3]. (b). Phase diagram of the charge order in Bi2201 [3].

In this experiment, we have also performed RIXS measurements at both O-K and Cu K-edge on UD25K and OD11K to study the orbital symmetry of charge order. As shown in Figure 3a, the charge order in UD25K looks similar at O edge and Cu edge, in terms of peak position and width. However, we could not found the CDW at O edge for OD11K. Considering the measured *L* values are different at O edge and Cu edge, it is not clear if this result implies the charge order in overdoped Bi2201 has a L-dependence. The requires futher investigation.

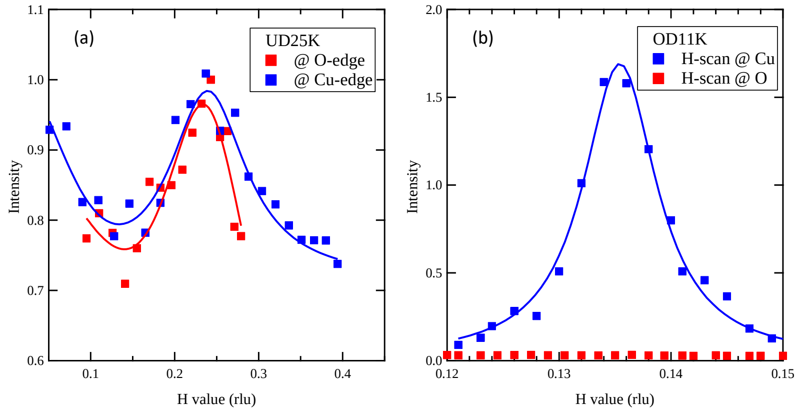


Figure 3: (a). REXS intensity of UD25K measured at positive H values, using σ polarization. (b). REXS intensity of OD11K measured at positive H values, using σ polarization

**References:**


1. Comin, R. et al. Charge order driven by Fermi-arc instability in $Bi_2Sr_{2-x}La_xCuO_{6+\delta}$. Science 343, 390-392 (2014).
2. Peng, Y. Y. et al. Direct observation of charge order in underdoped and optimally doped $Bi_2(Sr,La)_2CuO_{6+\delta}$ by resonant inelastic X-ray scattering. Phys. Rev. B 94, 184511 (2016).
3. Peng, Y. Y. et al. Re-entrant charge order in overdoped $(Bi,Pb)_{2.12}Sr_{1.88}CuO_{6+\delta}$ outside the pseudogap regime. Nature Materials 17, 697-702 (2018).