Experimental report

08/11/2024

Proposal: **CRG-3022**

Council: 4/2023

Title: Search for loop currents in the stripe-ordered (La,Ba)2CuO4

Research area: Physics

This proposal is a new proposal

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Samples: La2-xBaxcuO4 (x=1/8)

Instrument	Requested days	Allocated days	From	To
IN12	7	7	28/11/2023	11/12/2023
ORIENTEXPRESS	1	1	22/11/2023	23/11/2023

Abstract:

The abstract is in the scientific case pdf file.

Search for loop currents in stripe-ordered $(La,Ba)_2CuO_4$

I. Motivation

In most of hole doped cuprates [1], the polarized neutron diffraction has reported a quasi-long range **q**=0 magnetism, usually interpreted as the magnetic fingerprint of loop currents, except in lightly doped $La_{2-x}Sr_xCuO_4$ [2], where the **q**=0 magnetism remains 2D and at very short range. Among hole-doped cuprates, that family of compounds seems to favor the development of intertwined spin/charge uniaxial density wave, the so-called stripes. Interestingly, they can actually be generated out of a pair density wave state [3]. The short-range nature of the **q**=0 magnetism [2] was ascribed to its confinement within incipient bond- centered charge stripes, forming an array of 2-leg ladders. This proposal remained unnoticed, until recently, when a similar short-range **q**=0 magnetism was reported in 2-leg ladder cuprates [4].

Within the theoretical framework of intertwined order in mind, the objective of a previous experiment **Exp CRG#2722** was to probe the existence of a LC-like magnetism (q=0) in the stripe ordered compound $La_{2-x}Ba_xCuO_4$ (x ~1/8).

II. Outcome of Exp CRG#2722

The $La_{2-x}Ba_xCuO_4$ compound exhibits multiple structural phase transitions, on cooling, from the high temperature tetragonal phase (HTT) to the low temperature orthorhombic phase (LTO) at 250K and subsequently to the low temperature tetragonal phase (LTT) at 50K [5]. First, we did not observe noticeable changes of the flipping ratio across these phase transitions. Second, a weak reduction of the flipping ratio of the Bragg peak 101, FR_X, is observed at low temperature (see experimental report **CRG#2722**), meaning a possible weak 3D correlations of the q=0 magnetic signal in $La_{2-x}Ba_xCuO_4$ below ~ 50-70 K.

Further, based on the observations made in $(La,Sr)_2CuO_4$ [2] revealing that the q=0 magnetism remains 2D with no correlation along the c-axis, we looked for a quasi- 2D magnetic signal around (1,0,L). **Fig.1.a** shows the scan obtained in the SF_X channel across (H,0,0.8), away from the (1,0,1) nuclear Bragg peak, at T=100K in the LTO phase, revealing a Gaussian shaped peak centered at H=1. The same scan in the NSF_X channel (**Fig1.b**) shows only a featureless flat background. The XYZ-PA confirms the magnetic nature of the signal at 100K (**Fig.1.a,c**). The corresponding correlation lengths are short-range along the a-axis (about 12 Å) corresponding to the size of one Cu-O two-leg ladder. This magnetic signal thus exhibits the same characteristics as the q=0 magnetism reported in $(La,Sr)_2CuO_4$ hinting at a possible common origin for both magnetic phases, namely, confined loop current patterns.

The temperature dependence of the magnetic signal (**Fig.1.c**) suggests the vanishing of the magnetic scattering upon cooling down in the LTT phase, within error bars.

Put together, these observations suggest that the shot-range magnetic signal would be stronger (or only exist) above 50-70K, which maybe consistent with an enhancement of magnetic correlations lengths, at lower temperature, giving rise to magnetic scattering at (1,0,1) as suggested from the FR_X temperature dependence at (1,0,1).

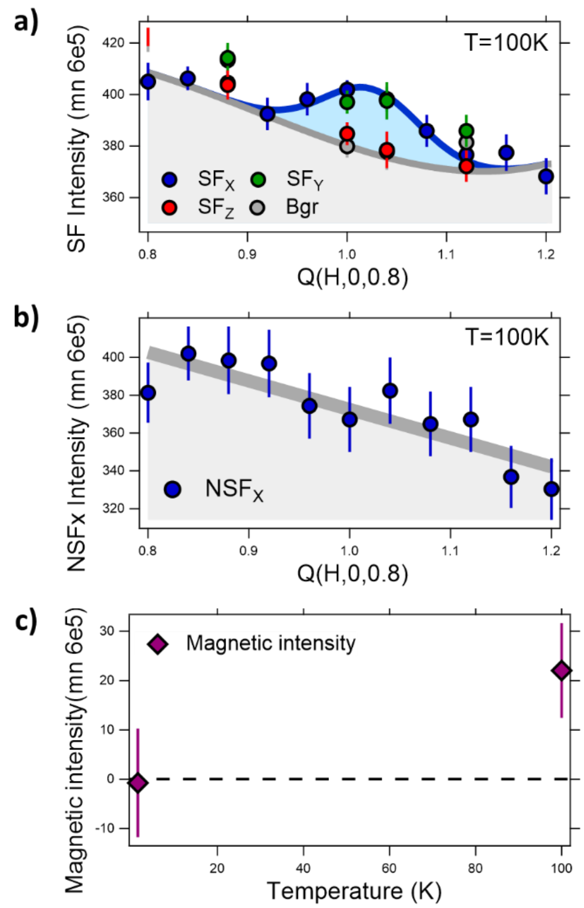


Figure 1. **a)** In the $SF_{X,Y,Z}$ channels revealing a magnetic signal centered at H=1 **b)** in the NSF_X channel. The gray shaded area in **(b)** corresponds to a fit to the background as extracted from XYZ-PA. **c)** Temperaturedependence of the magnetic scattering at (1,0,0.8) as extracted from XYZ-PA at 1.5 and 100K (From **CRG#2722**).

The purpose of the subsequent experiment **CRG#3022** was then to pursue our study to better characterize this novel magnetic phase and gain insight into its nature in the framework of intertwined orders by: **i)** Investigating the temperature dependence of the magnetic response at (1,0,0.8) in terms of intensity, correlation lengths, orientation of the corresponding magnetic moment. **ii)** Determining its temperature range of existence. **iii)** Studying its L-dependence in the LTO phase. **vi)** Determining its structure factor by investigating its existence at other H-values.

III. Outcome of Exp CRG#3022

The first aim of the experiment was to reproduce the measurement of the magnetic signal at (1,0,0.8) using XYZ-PA, taking advantage of the higher reactor power (56 MW) at this cycle, and using the same sample as in the previous experiment aligned in the (1,0,0)/(0,0,1) scattering plane.

Prior to the experiment, the sample had to be realigned and was a bit off-centered leading to some precession in the beam.

We first collected SF and NSF H-scans in the LTO phase at T=100K across (1,0,0.8). The data are shown in **Fig.2**. The NSF$_X$ scans is featureless, as seen previously. The counts are twice lower in the current run owing to a Cd shielding put around the Al sample holder to reduce the background level.

In the SF channel, although a signal of comparable amplitude to CRG#2722 could be fitted in the SF$_X$ polarization (about 30 cnts for a monitor of 6e5), the XYZ- PA reveals no magnetic scattering. Indeed, the SF$_Y$ and SF$_Z$ data points overlap with SF$_X$ data, within error bars.

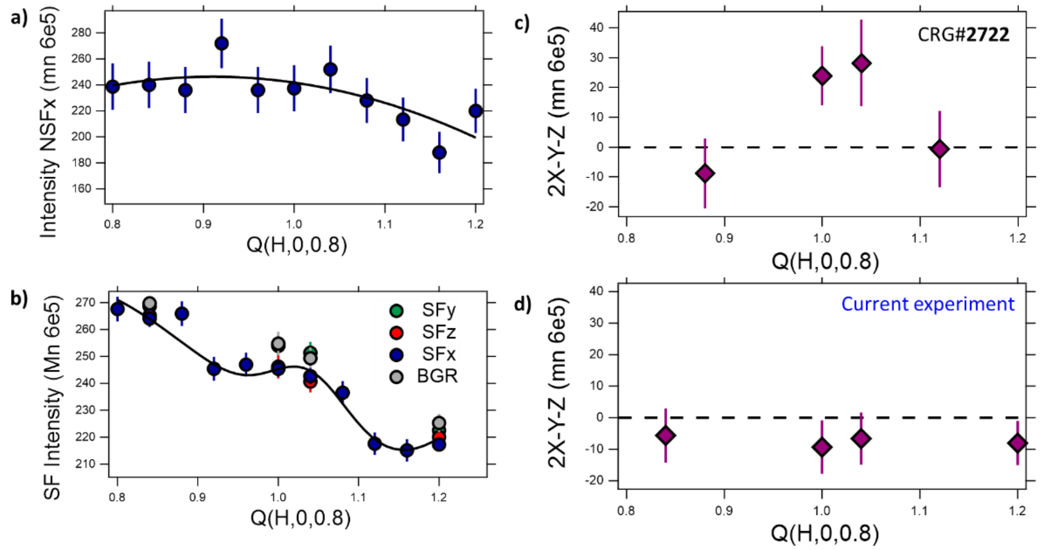


Figure 2. H-Scans **a)** in the NSF$_X$ channel. The line is a guide to the eye. **(b)** In the SF$_{X,Y,Z}$ channels revealing the same Gaussian like shape as in Fig.1.a, centered at H=1 in the SF$_X$ polarization. The gray points corresponds to the SF background as extracted from XYZ-PA. XYZ-PA along (H,0,0.8) **c)** Revealing the occurrence of magnetic scattering in CRG#2722 **d)** The absence of magnetic scattering for the current experiment.

In order to make sure that the sample composition did not evolve through aging, we performed a survey of the temperature dependence at the (1,0,0) Bragg peak, in the NSF$_x$ channel. The transition to the low temperature LTT phase was confirmed to occur at about 50K, as expected for a Ba-doping level of x=1/8 (**Fig.3.a**).

An additional survey of the intensity along the (1,0,L) direction in the three polarization directions (**Fig.3.b**). However, it quickly appeared that the SF$_Y$ scattering cross section was systematically higher than the SF$_X$ one, which led us to suspect a problem with the CRYOPAD tuning.

All of these measurements took 3.5 days (29/11-02/12 morning) and a reactor shutdown of 52h occurred during the weekend (02-04/12).

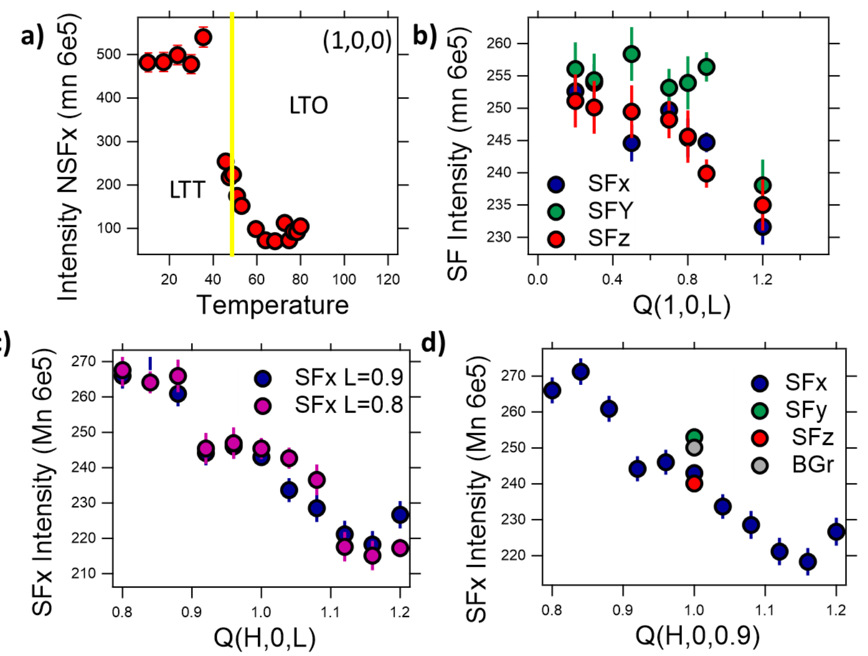


Figure 3. **a)** Temperature dependence of the (1,0,0) Bragg peak intensity in the NSFx channel showing the occurrence of the LTO to LTT structural transition at ∼50K. **b)** L-dependence of the SF intensity across the (1,0,L) line collected at 100K. **c)** H-scan in the SFx channel at L=0.8 and 0.9. **d)** XYZ-PA along (H,0,0.9) .

After the reactor ramp on 04/12, we collected a polarization matrix on different Nuclear Bragg peaks (±1,0,±1). We found out that the off-diagonal terms of the polarization matrix (XY and YX terms) were about 10%, which is much too high. By checking the instrumental area, we indeed noticed that CRYOPAD got stuck with a cryostat element (tube) leading to its misalignment with respect to the beam.

After alignment and tuning of CRYOPAD, we tested the polarization sum rule on a prototype antiferromagnetic material, a CuO sample in its antiferromagnetically ordered phase. We found out that the sum-rule was satisfied confirming the reliable tuning of CRYOPAD. We then started over with the LBCO measurements in the LTO phase at 100K.

We performed H-scans using XYZ-PA across (1,0,0.8) and (1,0,0.9). The comparison between the SF_X scans at L=0.8 and 0.9 is shown on **Fig.3.c**. The scans exhibit similar shapes but XYZ-PA shows no magnetic signal at H=1 (**Fig.3.d**) but the SF_Y cross section was still higher than the SF_X one.

We then moved to collecting the SF(X, Y and Z) cross sections on the (1,0,1) and (0,0,4) Bragg peaks as a function of temperature to see whether the previously seen effect on the FR (downturn in the LTT phase in CRG#2722) could be confirmed on the (1,0,1) position (**Fig.4**). The (0,0,4) peak was intended to be used as a reference to control the polarization. Unfortunately, no sign of the effect seen previously could be inferred from the current data and the SF_Y polarization channel intensity was again significantly higher than the SF_X one for both the (1,0,1) and (0,0,4) positions. The NSF_Y intensity was also higher than in the NSF_X channel, beyond error bars as indicated by the shaded areas in **Fig.4** at (1,0,1). The corresponding inverse flipping ratios were calculated ($1/FR = I_{SF}/I_{NSF}$). In all of the polarization channels, the 1/FR exhibit the same temperature dependence modulo a vertical shift with no hint to magnetic response.

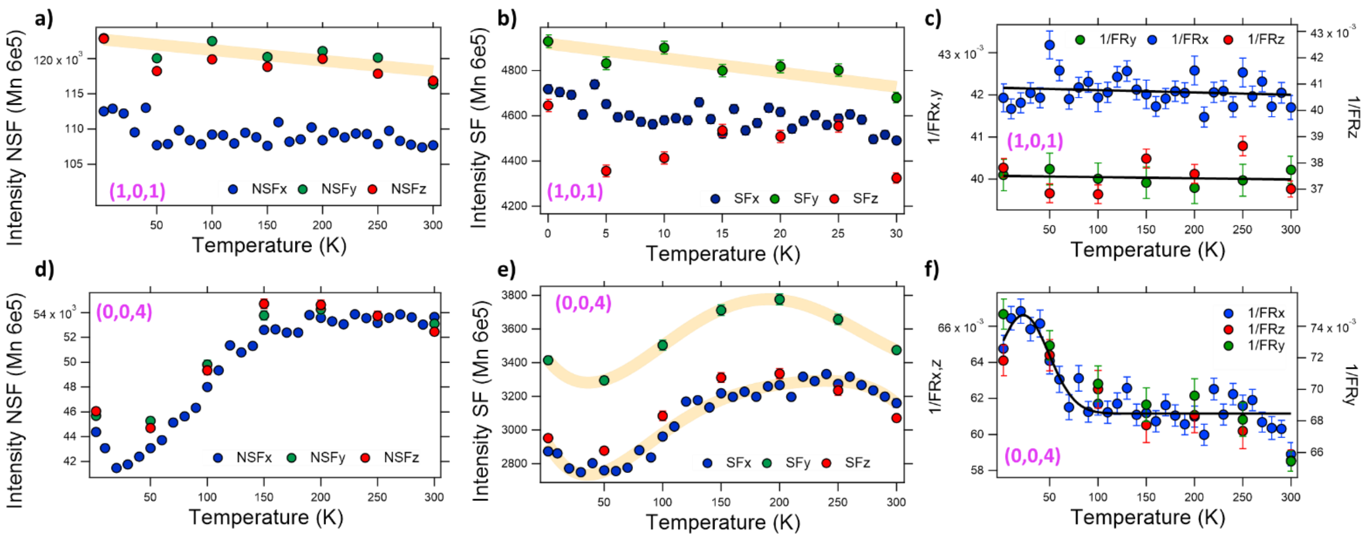
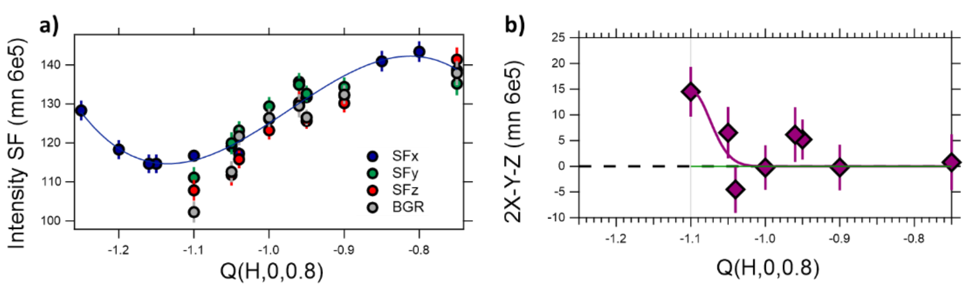


Figure 4. Temperature dependence of the SF **(a,d)**, NSF intensities **(b,d)** and inverse flipping ratios **(c,f)** in the X,Y and Z polarization directions for the (1,0,1) Bragg peak (top: a-c) and (0,0,4) Bragg peak (bottom: c-f) .

We spent the last two days (10-12/12) on counting scans in the (H,0,0.8), in the negative H-values region, and across (H,0,0) using XYZ-PA. The only indication for a magnetic signal was found at (-1.1,0,0.8) with a lower intensity than the previous experiment and a very different background shape in the SF_X channel when compared to the positive H-side scans (**Fig.5**).

Figure 5. a) H-Scans in the $SF_{X,Y,Z}$ channels across (-1,0,0.8) and the b) the corresponding magnetic intensity deduced from XYZ-PA revealing the occurrence of magnetic scattering at H=-1.1. The lines are guide to the eve.



If the signal given by XYZ-PA at (-1.1,0,0.8) is reliable, a possible explanation would be that that the sample was misaligned and strongly off-centered during the experiment. Indeed, once the sample extracted from the cryostat, and in addition to the precession due to the realignment of the sample, we noticed that the Cd shielding felt on the sample and lead to an additional tilt. This does however not explain why the Y polarization gave higher signal at (1,0,1) in either of the SF and NSF channels. A follow-up experiment is thus necessary to confirm on definitively disregard results from CRG#2722.

IV. References

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