Experimental report

27/10/2022

Proposal: **CRG-2722** **Council:** 10/2019

Title: Loop currents in (LaBa)2CuO

Research area:

This proposal is a new proposal

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Samples: La2-xBaxCuO4 x=1/8

Instrument	Requested days	Allocated days	From	To
IN3	1	1	15/02/2021	16/02/2021
IN12	5	5	18/02/2021	23/02/2021

Abstract:

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

- ## Scientific case:

A large variety of experiments indicate that discrete Z_2 symmetries (time reversal [1-3], inversion [5] and rotation [5-7]) are broken in the PG state. In his theory for the PG state [8,9], C.M. Varma has proposed that the PG state is associated with the spontaneous appearance of a magneto- electric loop current (LC) state, breaking the above-mentioned Z_2 symmetries, but preserving the lattice translation invariance. Among other experiments, polarized neutron scattering measurements [1] have provided a strong support to the existence of LCs. The LC model promotes the existence of a **q**=0 order, but such an order cannot gap out the Fermi surface and thus cannot account (alone) for the PG opening in hole doped cuprates.

The PG state is characterized by a fragmentation of the Fermi surface, with large portions gapped. A seemingly unrelated property of the PG state is that it exhibits discrete broken symmetries and uniform orders (**q**=0), likely connected to a QCP. Likewise, deep inside the PG state, various incipient modulated orders (**q** ≠0), in the spin, charge, electron-pair channels, show up and compete with the uniform (**q**=0) d-wave superconductivity.

The natural instinct one has to capture in this physics is to assign the different phases to competing order parameters. Alternatively, one way to rationalize such a complex phase diagram is to introduce the idea that multiple phases are born out of a primary state [10-16], namely the PG state itself. For instance, one can describe the PG state as originating from a vectorial (or multi-component) order parameter or the fractionalization of a (spin or pair) density wave state into several bosonic fields. The PG opening is related to somehow a Higgs mechanism. While the expectation value of each of the PG components can remain null, composite-orders can emerge from higher-combinations of the various components. Along this line of thought [10-16], a LC order or an electronic nematic order can be understood in terms of as ancillary [10-13] or preemptive [14-15] or vestigial [16] orders. While the phase diagram of hole doped cuprates could be seen as a soup of seemingly distinct electronic instabilities or competing orders, several theoretical approaches promote now the concept of intertwined electronic order connected to a mother state. These orders can be uniform (**q**=0) such as LC-like states, but also modulated (**q** ≠0), of density wave type.

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 LCs. Except in lightly doped $La_{2-x}Sr_xCuO_4$ [17], 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 [14]. The short-range nature of the **q**=0 magnetism [17] 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 [18].

- ## Outcome of experiment CRG#2722

Within the theoretical framework of intertwined order in mind, the objective of **Exp CRG#2722** was to probe the existence of a LC magnetism (**q**=0) and orbital density wave (**q** ≠0) in the stripe ordered compound $La_{2-x}Ba_xCuO_4$ (x ~1/8) [19]. We looked for a quasi- 2D signal around (1,0,L).

The sample was aligned in the (1,0,0)/(0,0,1) scattering plane. We used a neutron wavevector k_f= 1.5A^{-1}. The outgoing beam polarization was achieved using a Heusler analyzer and the polarization analysis was ensured using CRYOPAD.

The flipping ratio was measured on two different Bragg peaks (0,0,4) and (1,0,1) and was found to be around 12 and 25, respectively, for the X,Y,Z polarizations.

First measurements were dedicated to the determination of the temperature dependence of the scattered intensity in the six $SF_{X,Y,Z}$ and $NSF_{X,Y,Z}$ channels (Figure 1) at the (1,0,1) Bragg position. We systematically performed A3 and A4 scans to realign the sample at each temperature.

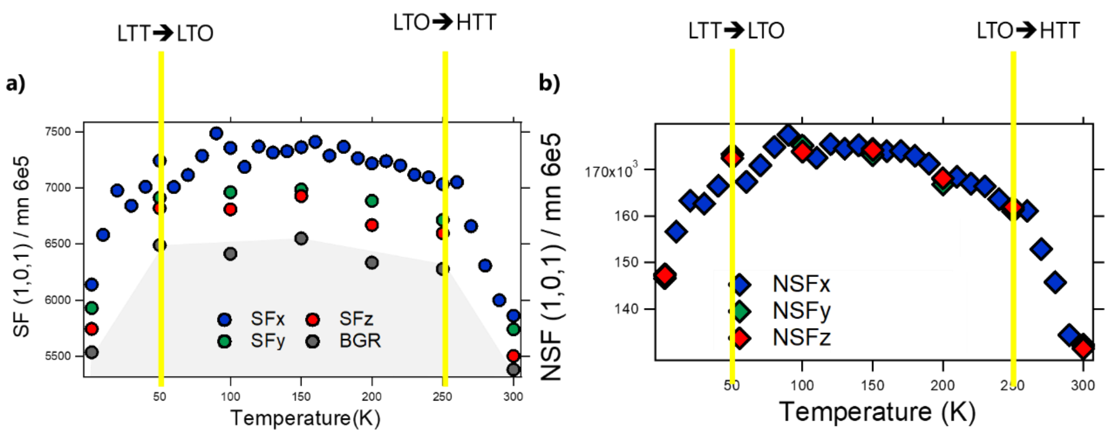

Figure 1. Temperature dependence of the scattered intensity at (1,0,1) measured in a) $SF_{X,Y,Z}$ channels and b) $NSF_{X,Y,Z}$ channels. The gray shaded area corresponds to the background as deduced from the XYZ-PA The yellow lines indicate structural transitions as defined in the text.

Measurements performed in the NSF channel (**Fig.1.b**) highlight the structural 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, as expected from literature [20].

Owing to the polarization leakage from the NSF to the SF channel, the same features are seen in the SF measurements. **Figure 2** shows the evolution of the corresponding flipping ratios $FR_{X,Y,Z}$ versus temperature. First, one can notice that no sign of anomaly related to the structural transitions is present meaning that the ratio of NSF/SF is reliable, which is, for instance, to contrast with the study reported in $La_{2-x}Sr_xCuO_4$ in [21]. However, one can also see that the flipping ratio is not perfectly homogeneous, even at room temperature and with the use of CRYOPAD. Next, while the $FR_{y,z}$ ratios follow a monotonic temperature dependence, FR_X exhibits a dip below ~ 70K which may be related to the occurrence of magnetic scattering on top of (1,0,1) below this temperature (hatched area in **Fig.2**).

Based on the observations made in $(La,Sr)_2CuO_4$ [17] revealing the existence of 2D planar magnetic correlations, we next performed a scan at (H,0,0.8) at T=100K, which further allowed to get rid of the polarization leakage effects at the strong Bragg peak position (1,0,1).

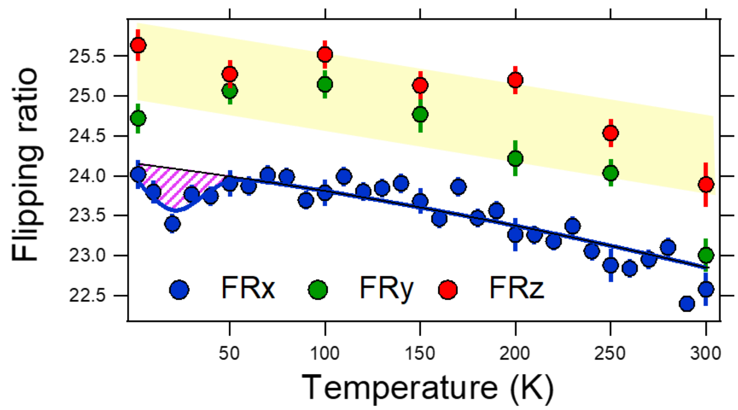

Figure 2. Temperature dependence of the flipping ratio measured in the X,Y and Z channels at (1,0,1)

Fig.3.a shows the scan obtained in the SF_X channel across (H,0,0.8) channel at T=100K in the LTO phase, revealing a Gaussian shaped peak centered at H=1. The same scan in the NSF_X channel (**Fig.3.b**) shows only a featureless flat background. The polarization analysis reveals a clear magnetic signal at 100K (**Fig.3.a, c**) with short-range correlation length along the a-axis of ≈ 12 Å.

The temperature dependence of the magnetic signal at the same Q-position (**Fig.3.c**) suggests the vanishing of the magnetic scattering upon cooling down in the LTT phase, within error bars. This suggests that the short-range magnetic signal would be stronger (or only exist) in this temperature range. This may be consistent with an enhancement of magnetic correlations at lower temperature giving rise to magnetic scattering at (1,0,1) as suggested from the FR_X temperature dependence in **Fig.2.**

This study needs to be complemented by measuring the full temperature dependence of the short-range 2D magnetic signal to confirm this scenario.

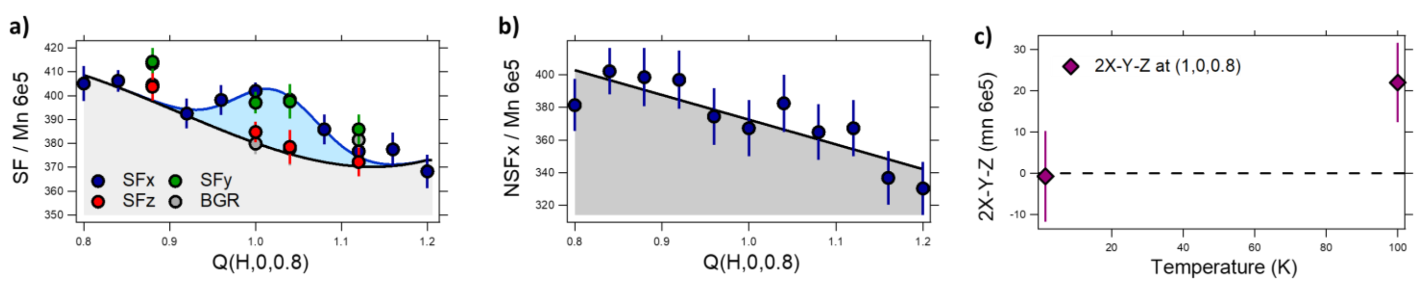

Figure 3. H-scan across (H,0,0.8) at 100K **a)** In the SFX,Y,Z channels revealing a magnetic signal centered at H=1 **b)** in the NSFx channel**.** The gray shaded area in (a) corresponds to a polynomial fit to the background as extracted from XYZ-PA. **c)** Temperature dependence of the magnetic scattering at (1,0,0.8) as extracted from XYZ-PA at 1.5 and 100K.

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