Experimental report

18/09/2023

Proposal: **DIR-283** **Council:** 10/2022

Title: MAGNETIC TEXTURE IN THEPSEUDOGAP STATE OF CUPRATES

Research area: Physics

This proposal is a new proposal

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Samples:

Instrument	Requested days	Allocated days	From	To
D33	2	2	25/06/2023	27/06/2023

Abstract:

MAGNETIC TEXTURE IN THE PSEUDOGAP STATE OF SUPERCONDUTING CUPRATES

Experimental team: *Nicolas Martin, Philippe Bourges, William Liège, Dalila Bounoua, Yvan Sidis (LLB)*

In high-temperature superconducting cuprates, an intra-unit-cell (IUC) **q=0** magnetism develops within the pseudogap (PG) state [1] below an onset temperature T*. This origin of this magnetism is usually associated with a magneto-electric loop current (LC) state breaking both time and parity symmetries, but preserving the lattice translation invariance. In a series of polarized neutron diffraction (PND) studies, we have recently uncovered the existence of a new form of magnetism in the PG state of superconducting cuprate $YBa_2Cu_3O_{6+x}$ [2,3]: it occurs at the planar wave vector (0.5,0) ≡ (0,0.5) and has to be described by a 2x2 larger unit cell. Together with previous reports of the **q=0** magnetism in cuprates [1] (that is developing at longer distance), we infer a unique hidden magnetic texture of the CuO_2 unit cells hosting loop currents/anapoles [2,3].

Lorentz Transmission Electronic Microscopy (LTEM) has very recently reported skyrmionic magnetic clusters in the pseudogap state of high-Tc cuprates [ref 4 published online on 23 February 2023]. The magnetic texture observed by LTEM has an averaged radius of about 25 nm, which should be directly observable using Small Angle Neutron Scattering (SANS). It can be fully related to our newly discovered magnetic response in the phase diagram of high-Tc cuprate $YBa_2Cu_3O_{6+x}$ [2,3] from which we infer a magnetic texture of similar size.

In the experiment DDT-283 on D33, we have studied one sample of detwinned underdoped $YBa_2Cu_3O_{6.6}$ array where the pseudogap state has been well-characterized using polarized neutron diffraction [2,5]. The sample is superconducting with Tc=61K determined by a susceptibility measurement conducted with the PPMS at LLB after the D33 experiment.

The SANS experiment on D33 has been mostly performed at neutron wavelength of l=6 Å with a couple of scans at l=12 Å. At each temperature, a transmission scan has been made to normalize the intensity of the scattered beam. The SANS intensity data in logarithmic scale in the (H,0,0)/(0,K,0) plane is shown in Fig. 1a (the sample is slightly tilted from the vertical). The red areas (sector 2) correspond to the axes directions a* and b* whereas the blue areas (sector 1) are along the diagonals directions a*±b*. According to the magnetic texture reported in LTEM, one should here observed a magnetic signal at small angle with a maximum at a Q-position inversely proportional to the total cluster size. Unfortunately, such a maximum does not show up in our data when summing up the intensity over all sample orientations due to the large nuclear background and the possible distribution of magnetic length scales.

Instead, one nevertheless observes a specific intensity distribution at lower momentum with more intensity integrated in the sector 2 (along the principal axis or the Cu-O direction) than in the sector 1 (along the diagonals). The temperature dependence of radial integrated intensity in sector 2 normalized to room temperature reminds the one of the magnetic intensity reported on the Bragg peak through inverse flipping ratio at the (1,0,0) Bragg peak in the same sample [5] whereas the same integration in sector 1 does not change noticeably versus temperature(Fig. 1b). This suggests a weak magnetic signal (≈1.5 % of the total background) occurring over a wider length scale (say around q ~ 0.005 to 0.02 $Å^{-1}$, meaning a typical length scale in the range 30-125 nm). This is in a rather good agreement with LTEM data which points out spin texture features with a vortex-like magnetization density in the CuO2 sheets of ~100 nm. A magnetic field study on D33 with horizontal magnetic field is the next step to prove that signal is magnetic in origin.

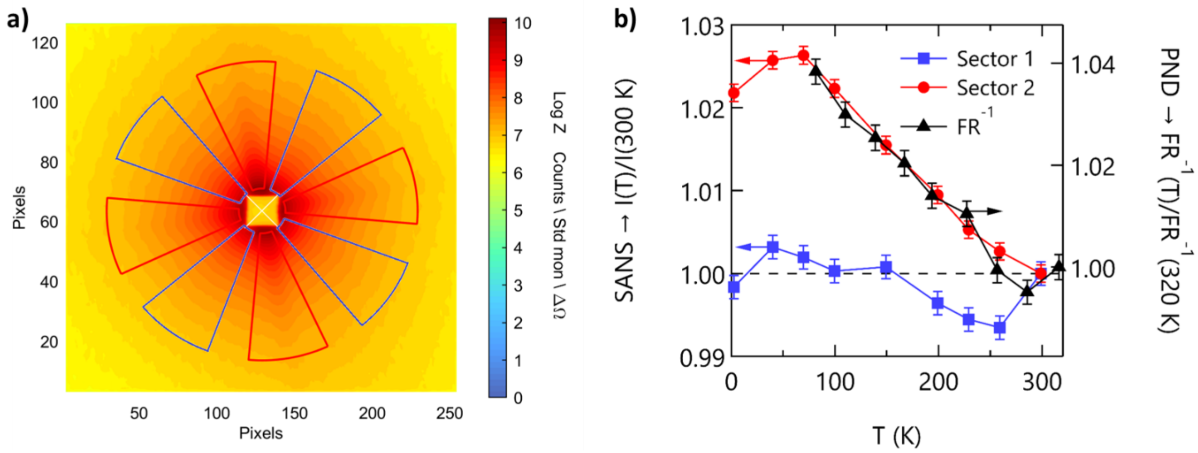

Figure 1: a) SANS map collected with Q in the (H,0,0)/(0,K,0) plane indicating the regions corresponding to Sector 1 and 2 in **(b)**. **b)** Temperature dependence of the integrated intensity in Sectors 1 and **2 (parallel to the a and b-axis)** showing the onset of an extra intensity in Sector 2. The temperature dependence follows the one of the inverse flipping ratio (FR^{-1}) obtained at the (1,0,0) position in the same sample, showing the onset of the q=0 magnetism [5].

References:

[1] Ph. Bourges, D. Bounoua, Y. Sidis, Comptes Rendus Physique, 22(S5) 7-31 (2021).
[2] D. Bounoua et al., Comm. Phys 5, 268 (2022).
[3] D. Bounoua et al., arXiv:2302.01870 (2023), under review in Phys. Rev. B.
[4] Z. Wang, et al, Nature 615, 405–410 (2023).
[5] L. Mangin-Thro et al., Phys. Rev. Lett. 118, 097003 (2017).