Experimental report

08/09/2022

Proposal:	**CRG-2822**	**Council:**	10/2020
Title:	Orbital magnetism in two-leg ladder cuprate		
Research area:			

This proposal is a new proposal

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Samples: YBa2CuO6.9

Instrument	Requested days	Allocated days	From	To
IN22	6	6	26/05/2021	01/06/2021

Abstract:

bi-axial magnetism in underdoped $YBa_2Cu_3O_{6.6}$

Scientific case

Despite decades of intense research, the enigmatic pseudo-gap (PG) phase of superconducting cuprates remains an unsolved mystery. In the last 15 years, various symmetry breakings in the PG state have been discovered, including intra-unit cell (IUC) or **q**=0 magnetism that preserves the lattice translational (LT) symmetry, but breaks time-reversal symmetry and parity, and an incipient charge-density-wave order that breaks the LT symmetry. However, none of these states can (alone) account for the partial gapping of the Fermi surface. Recently, we reported polarized neutron diffraction evidence for a hidden LT-breaking magnetism [1]. Our measurements reveal magnetic correlations in two different underdoped $YBa_2Cu_3O_{6.6}$ single crystals that start at the PG onset temperature with i) a planar propagation wave vector (π, 0) ≡ (0, π) (Fig. 1), yielding a doubling or quadrupling of the magnetic unit cell, and ii) magnetic moments that mainly point perpendicular to the CuO_2 layers. This **q**=π magnetism is rather 2D and short-range, indicative of clusters of 5-6 unit cells within the CuO_2 planes.

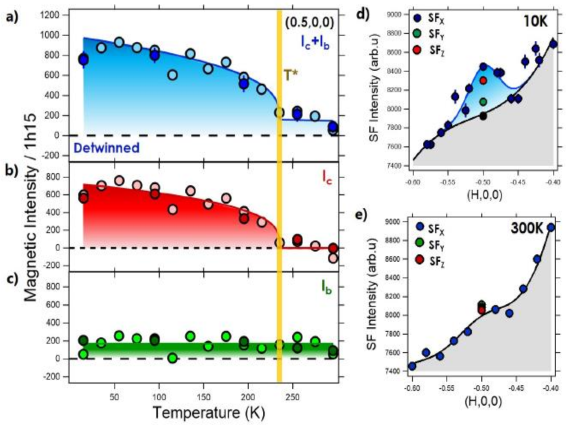

Figure 1 Temperature dependence of the biaxial magnetism in twin-free $YBa_2Cu_3O_{6.6}$ [1] measured at (0.5,0,0): (a) full magnetic scattering; (b) out-plane magnetic scattering I_c; c) in-plane magnetic scattering I_b. (d-e) longitudinal H-scans across (0.5,0,0) in the Spin Flip (SF) channel with the neutron spin polarization parallel to X at 10 K and 300 K. Full polarization analysis in the SF channel at (0.5,0,0) is shown, with the set of three orthogonal polarizations X, Y, and Z indicated in blue, green, and red, respectively.

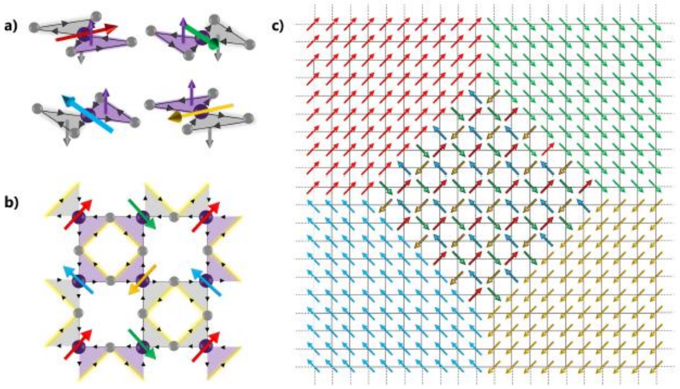

*Figure 2 Schematic of the hidden magnetic texture with **q**=π short range and **q**=0 magnetisms observed in polarized neutron diffraction. (a) Four possible degenerate ground states of loop currents (LCs). The grey and purple arrows represent magnetic moments along the c axis whereas the four other arrows represent toroidal moments carried by the LC state. (b) 2x2 LC pattern that can account for the **q**=π magnetism. (c) Example of 2D magnetic texture with 20x20 unit cells paved by toroidal moments (LC states). The central bubble with 2x2 LC patterns gives rise to the **q**=π short-range magnetism, whereas the **q**=0 magnetic signal arises from the larger color domains.*

In previous studies, we also reported the existence of long-range **q**=0 magnetism, which was interpreted as the magnetic hallmark of loop currents within the CuO_2 unit cell, as proposed by C. M. Varma. Put together, the **q**=0 and **q**=π magnetic scatterings observed by polarized neutron diffraction could actually belong to a unique complex magnetic texture of the CuO_2 unit cells hosting loop currents (Fig. 2). Such a magnetic texture would be made of 4 large domains with **q**=0 loop-current (LC) order (with LC patterns rotated by 90° from one domain to the next) and, at their corner, a bubble of intertwined LC giving rise to the **q**=π magnetic response. The existence of such a large supercell with LC re-arrangement modifies the LT symmetry and can contribute to the PG.

Outcome of the #CRG 2822 experiment

The polarized neutron scattering experiment was performed on IN22 equipped with spherical polarization set: Both Heusler monochormator and analyzer were polarizing the neutron beam. CRYOPAD allows the full XYZ polarization analysis and, owing to its zero magnetic field chamber, prevents measurements in the superconducting states from a depolarization due to trapped magnetic field within sample. The scattered intensity for the experiment was significantly lowered by: (i) a reactor operating at 40 MW only and the use of two large PG filters to remove the high order contamination. For elastic measurements, the neutron energy was set to 14.7 meV.

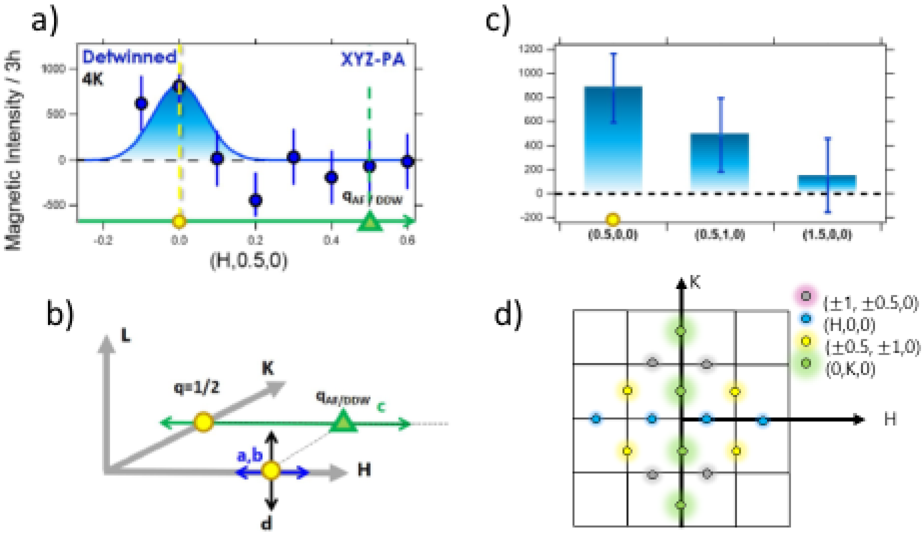

Figure 3 Full magnetic intensity at 4K, obtained after a full XYZ polarization analysis (XYZ-PA): a) H-scan across (0.5,0,0). b) Scans in moment space, c) Mean magnetic intensity (XYZ-PA) at (0.5,0,0) or (0,0.5,0) + τ, where τ stands for a wave vector of the reciprocal lattice. d) Different magnetic wave vectors measured on IN22.

Our Twin free $YBa_2Cu_3O_{6.6}$ sample is made of a few tenth of co-aligned single crystal, glued on an Al- Plate. While for early measurements, the sample was set in the (100)/(001) scattering plane to study the $\mathbf{q}=\pi$ magnetic response around (0.5,0,L), the sample was aligned in (100)/(010) scattering plane in the present experiment, so that wave vector of the (H,K,0) were accessible. The flipping ratios measured on the nuclear Bragg reflection (2,0,0) and (0,2,0) were 18 and 15, respectively. The flipping ratios appeared quite stable when rotating the neutron spin polarization in the X, Y and Z channels.

Our measurements on IN22 demonstrate that the $\mathbf{q}=\pi$ magnetism exists at (0.5,0,0) and (0,0.5,0), but remains absent at (0.5,0.5,0) (Fig.3 a-b). Furthermore, the magnetic scattering can be measured at several wave vectors, equivalent by symmetry. The magnetic scattering is also sizeable in the 1st, 2nd and 3th Brillouin zones, while its intensity decreases at large |Q|, as expected for a signal weighted by the square of a magnetic form factor (Fig. 3.c-d). The results of Fig. 3.a and 3.c were included in Fig.2 of reference [1].

REFERENCES*:*

[1] D. Bounoua et al., to appear in Comm. Phys, arXiv 2111.00525