Experimental report

05/01/2022

Proposal: 4-02-600 **Council:** 10/2020

Title: Search for a bi-axial magnetic response in YBa2Cu3O7-d

Research area: Physics

This proposal is a new proposal

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Samples: YBa2Cu3O7-d

Instrument	Requested days	Allocated days	From	To
IN3	1	1	10/02/2021	11/02/2021
THALES	7	7	08/02/2021	15/02/2021

Abstract:

The purpose of the proposal is the study of a new magnetic response in the phase diagram of high temperature superconducting cuprate YBa2Cu3O6+x. This new magnetism develops at the wave vector Qo(0.5,0,L) and seems tightly bound to the physics of the mysterious pseudo-gap state. We propose to characterize its momentum, temperature and low energy dependences in an optimally doped YBa2Cu3O7-d sample using full polarization analysis. We apply for 7 days of beam time on the cold TAS instrument THALES equipped with CRYOPAD.

Scientific council: 10/2020

Proposal: 4-02-600

Title: Search for a bi-axial magnetic response in $YBa_2Cu_3O_{7-\delta}$

Main proposer: SIDIS Yvan

Proposers:

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Environments: CO, CPA

Instrument	Requested days	Allocated days	Grade	Schedules
IN3	1	1		From 10/02/2021To 11/02/2021
THALES	7	7	A9.0	From 08/02/2021To 15/02/2021

SCIENTIFIC CASE:

The generic phase diagram (Fig. 1) of hole doped cuprate superconductors show various electronic instabilities. In the underdoped regime, the d wave superconducting (SC) state seems to compete with an incipient bi-axial charge density wave (CDW) with a d-wave structure factor. Both states appear deep inside the so-call pseudo-gap (PG) state, which gaps large portions of the Fermi surface and keeps Fermi arcs only. Concomitantly, an intra-unit-cell (IUC) magnetism develops with the PG state [1,2]. This state is usually associated a magneto-electric (ME) loop current (LC) state breaking both time and parity symmetries, but preserving lattice translation invariance [3]. The breaking of these Ising (local) symmetries cannot open the PG. Interestingly, a similar IUC magnetism has also been reported in the spin liquid state of 2-leg ladder cuprates [4]

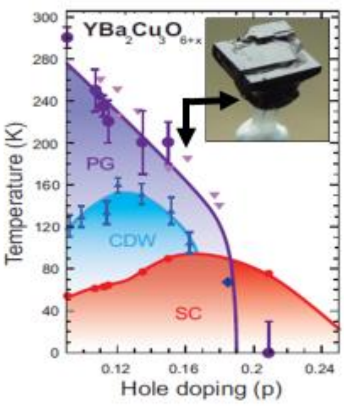


Fig 1 : *phase diagram of $YBa_2Cu_3O_{6+x}$ as a function of = the hole doping (p).*

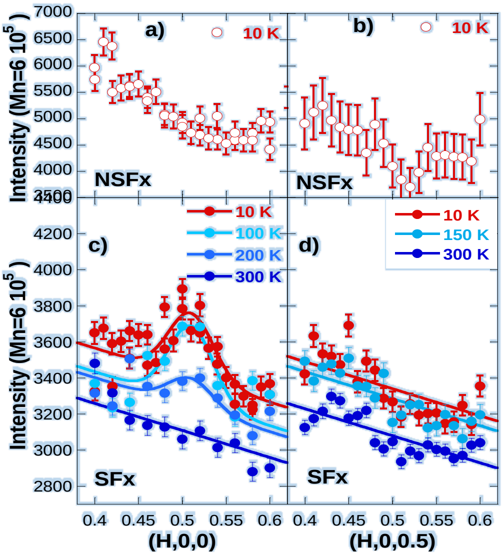
SAMPLE (insert): *Recently, 2 large single crystals of $YBa_2Cu_3O_{7-\delta}$ (3g and 6g) without green phase were successfully grown by Pr. Xin Yao at the school of Physics and astronomy of the Shangai University, by top-seeded solution growth process.*

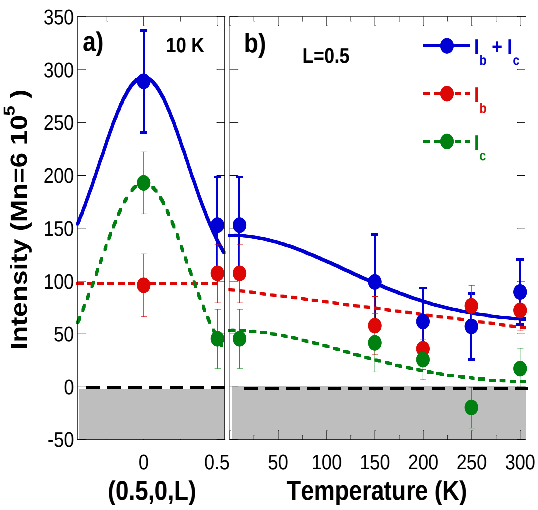
These samples are different from most of the large $YBa_2Cu_3O_{6+x}$ single crystals which always contain ~15% of Y_2BaCuO_5 powder (green phase). This impurity phase, exhibits an AF order below 28 K and its low energy paramagnetic response widely screens the detection intrinsic magnetic scatterings. Our fully oxygenated samples exhibit a T_c of 92.7 K, corresponding to a hole doping p=0.17.

Over the years, the concept of intertwined orders has emerged [5-8]. It is based on the existence of a mother state with an intrinsic multi-component nature. Higher order combinations of its components can generate *auxiliary* phases. Being born out of the fluctuations of the mother state components, they can appear at high temperature (*preemptive* orders) and carry only a subset of the symmetry broken in the ground state (*vestigial* orders). The ME-LC state could be one of these auxiliary states, but, in addition, it could exist other charge current DW states, yielding an orbital magnetic response at finite wave vector. Alternatively [9], it has been proposed that a specific and coherent arrangement of fourfold degenerates LC domains could lead at a superstructure, breaking the lattice translation invariance. Once again, an orbital magnetic response at finite wave vector should appear.

THE NEW FEATURE

We have performed a series of polarized neutron diffraction studies to uncover the existence of new forms of magnetic hidden in the phase diagram of superconducting cuprates. In our studies of underdoped $YBa_2Cu_3O_{6.6}$ compound [10], we systematically observed a new static magnetic response at the planar wave vector $\mathbf{Q}_o$=(0.5,0) . The observation was made on very different samples: (i) twined and untwined, (ii) grown with magnetic green phase or without (Fig.1) and (iii) on different instruments equipped with various experimental setup (CRYOPAD on IN22 and THALES at ILL and MuPAD on 4F1 at LLB). Gathering all information available so far, one can say that the magnetic scattering does not come from the CuO chains that play the role of charge reservoirs in $YBa_2Cu_3O_{6+x}$. The magnetism belongs to the CuO_2 planes and seems to be bi-axial, being observed at $\mathbf{Q}_o$=(0.5,0) and/or (0, 0.5). Rocking scans rule out a spurious scattering originating for magnetic powder lines (such as CuO). This conclusion is further confirmed by the absence of nuclear scattering associated with the known powders that may be present in $YBa_2Cu_3O_{6+x}$. The magnetic signal gradually settles in on cooling down from room temperature. Its remains at short range in the CuO_2 planes, with vanishing correlations between neighboring planes.





Mn=6 10^5 (~5 min)

FIG 2: *H scan in the NSFx and SFx channels across Q=(0.5,0, 0) (a,c) et Q=(0.5,0, 0) (b,d), measured at several temperatures.*

Fig 3 : *full (I_b+I_c), in-plane (I_b) ,d out-of-plane (I_c) magnetic scatterings : a) L scan at (0.5,0,L), b) T- dependence at (0.5,0,0.5)*

OUTCOME OF THE THALES EXPERIMENT

Let us focus on the recent results obtained on THALES in our $YBa_2Cu_3O_{7-\delta}$ sample (Fig. 1). On THALES the elastic measurements were carried out with a neutron wave of 1.5 $Å^{-1}$. For a Full polarization analysis, one needed at least a counting time of 30 min per polarization.

As shown in Fig 2.a,c, there is no peaked scattering present in the H scan around $\mathbf{Q}_o$ in the non-spin flip (NSF) channel. In the spin flip (SF) channel, a magnetic scattering shows up at L=0 (Fig 2.b) and decreases at high temperature. A similar signal is not visible at L=0.5 (Fig 2. d), but it could remain hidden by non-uniform line shape of the SF background, that could mimic the line shape of the NSF one. The full polarization analysis (Fig. 3) suggests the existence of a magnetic signal located at L=0, rather broad along L. The out-of-plane magnetic response dominates that signal, which decays with increasing T. An additional in-plane magnetic component is also present, but it seems to depend hardly on T and L.

Our polarized neutron diffraction measurements, in underdoped $YBa_2Cu_3O_{6.6}$ [10] and optimally doped $YBa_2Cu_3O_{7-\delta}$ single crystals reveal magnetic correlations with a planar propagation wave vectors $\mathbf{Q}_o$, yielding a doubling or quadrupling of the magnetic unit cell. The magnetic scattering is dominated by magnetic moments mainly pointing perpendicular to the CuO_2 layers. Such an out-of-plane magnetic response seems to settle around the PG temperature. This lattice translation breaking magnetism is always at short range, suggesting the formation of clusters of a few unit cells

We recently proposed a hidden magnetic texture of CuO_2 unit cells hosting loop currents (see fig. 4 in Ref. [10]). Our picture unifies the observation of a $\mathbf{Q}_o$ magnetism together with the previously reported IUC magnetism. This picture holds for the out-of-plane magnetic response.

In addition, we also observed an in-plane response: very weak in underdoped $YBa_2Cu_3O_{6.6}$ [10], but more significant in optimally doped $YBa_2Cu_3O_{7-\delta}$ (Fig. 3). At variance with the out-plane response, it displays a rather weak temperature dependence. The origin of that in-plane magnetic response remains to be understood.

REFERENCES

[1] Mangin-Thro,et al., Nat Comm. 6 (2015), p. 7705
[2] Y. Tang, et al., Phys. Rev. B 98 (2018), p. 214418,
[3] M. Varma,, Phys. Rev. B 73 (2006). p. 155113
[4] D. Bounoua et al, Comm. Phys 3 (2020), no. 1, p. 123,
[5] R.M. Fernandes, Annual Review of Condensed Matter Physics 10, 133 (2019)
[6] D. F. Agterberg, et al. Phys. Rev. B 91 (2015), p. 054502,
[7] M. S. Scheurer & S. Sachdev, Phys. Rev. B 98 (2018),p. 235126
[8] S. Sarkar et al., Phys. Rev. B 100 (2019), p. 214519,
[9] C. M. Varma, Phys. Rev. B 99 (2019), p. 224516,
[10] D. Bounoua et al., arXiv :2111.00525