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Article

Keywords: pseudo-gap (PG) phase, LT-breaking magnetism, $\text{YBa}_2\text{Cu}_3\text{O}_{6.6}$

Posted Date: November 30th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1067175/v1>

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Version of Record: A version of this preprint was published at Communications Physics on November 2nd, 2022. See the published version at <https://doi.org/10.1038/s42005-022-01048-1>.

Hidden Magnetic Texture in the Pseudogap Phase of High-Tc $YBa_2Cu_3O_{6.6}$

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November 10, 2021

Despite decades of intense researches, 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, spanning an intra-unit cell (IUC) magnetism, preserving the lattice translational (LT) symmetry but breaking time-reversal symmetry and parity, and an additional incipient charge density wave breaking the LT symmetry upon cooling. However, none of these states can (alone) account for the partial gapping of the Fermi surface. Here we report a hidden LT-breaking magnetism which is crucial for elucidating the PG puzzle. Our polarized neutron diffraction measurements reveal magnetic correlations, in two different underdoped $YBa_2Cu_3O_{6.6}$ single crystals, that settle at the PG onset temperature with i) a planar prop-

agation wave vector $(\pi, 0) \equiv (0, \pi)$, yielding a doubling or quadrupling of the magnetic unit cell and ii) magnetic moments mainly pointing perpendicular to the CuO_2 layers. The LT-breaking magnetism is at short range suggesting the formation of clusters of 5-6 unit cells that, together with the previously reported IUC magnetism, yields a hidden magnetic texture of the CuO_2 unit cells hosting loop currents.

The phase diagram of high temperature cuprate superconductors is dominated by the mysterious PG phase overhanging the unconventional d-wave superconducting (SC) state [1, 2, 3]. A fundamental property of the PG is a partially gaped electronic spectrum whose origin has been under hot debate and deep experimental and theoretical scrutinies since its discovery [4]. A wide set of experimental results report the onset of broken discrete Ising (Z_2) symmetries at the same characteristic temperature T^* where the electronic PG opens [5]. The discrete broken symmetries are: lattice rotation (C_4) [6, 7, 8], interpreted in terms of an (Ising) nematic order, inversion or parity (P) as shown by second harmonic generation [9] measurements and time-reversal (T) as reported by polarized neutron diffraction (PND) [10, 11, 12, 13, 14, 15, 16], circularly polarized angle resolved photo-emission spectroscopy [17] and muon spin spectroscopy [18]. The T and P symmetry breakings are usually associated with a translationally invariant or Intra-Unit Cell magnetism ($q=0$ or IUC-magnetism), either carried by loop currents (LCs) [19, 20, 21, 22, 23] or by magnetic multipoles [24, 25, 26]. The detection of such objects is extremely challenging owing to the weakness of the corresponding signal, which is further partly hidden by the structural response during a scattering experiment [10, 11, 12, 13, 14, 15, 16]. However, to date, the reported $IUCs$ pattern preserves the LT symmetry. A large Fermi surface is thus conserved and none of the $IUCs$ related broken discrete symmetries can induce the needed electronic gap [27]. Meanwhile, the Fermi electron pockets observed at high magnetic field and low temperature in the PG phase [2, 3] must originate from a phase breaking LT

symmetry.

In the same region of the phase diagram, at somewhat lower temperature than T^* , modulated charge density wave (CDW) that competes with SC and breaks the LT and C_4 symmetries were extensively reported [1, 2, 8]. The short-range d-wave CDW induces a lattice superstructure leading to a bi-axial response at incommensurate planar wave-vectors in reciprocal space $q_{CDW}=(0,\pm\epsilon)$ and/or $(\pm\epsilon,0)$, with $\epsilon \sim 0.3$ in reduced lattice units (*r.l.u*) in $YBa_2Cu_3O_{6+x}$ (YBCO). At zero magnetic field, CDW modulations are quasi-2D and weaken when entering the SC state at $T < T_c$. Upon applying either an external magnetic field along the c -axis [28] or a uni-axial pressure along the a -axis [29], 3D CDW correlations develop with a uni-axial character along the b -axis (direction of the underlying CuO chain in YBCO, see Fig. 1.a). Although the incipient CDW breaks LT symmetry, its onset temperature T_{CDW} remains well below T^* , deep into the PG phase, and can thus not be alone at the origin of the opening of the electronic gap. This conclusion is further reinforced by recent Hall transport measurements [30].

To describe this manifold problem and reconcile the seemingly unrelated discrete symmetry breaking and the occurrence of the electronic gap, new theoretical approaches invoking the concept of intertwined states were elaborated [1]. Apart from $IUC - LCs$ magnetism and modulated CDW , several studies focused on the search for unconventional magnetic correlations involving alternative symmetry breaking charge current patterns in cuprates. For instance, starting from a collinear homogeneous antiferromagnetic (AF) Mott insulator (zero hole-doping, localized $S = \frac{1}{2}$ spins on Cu atoms) with a magnetic response at the planar wave-vector $q_{AF}=(0.5,0.5)$, hole-doping was proposed to destabilize the AF state towards a spin-liquid state characterized by a staggered flux phase (π -flux) [31], also described as a d -wave charge density wave (DDW) state [32]. This state exhibits staggered LCs , yielding an orbital magnetic response at $q_{DDW}=q_{AF}$. Note, however, that the spin moments are locked within the CuO_2 layers (planar anisotropy) [33], whereas the LCs orbital moments are expected to be perpen-

dicular to the CuO_2 layers. Despite several attempts, neutron diffraction measurements failed to prove the existence of such a phase [14, 34].

Here, we report the discovery of magnetic correlations at commensurate planar $\mathbf{Q}$ -wave-vectors $(q, 0) \equiv (0, q)$ with $q = 1/2$ that appear to be tightly bound to the PG physics in the underdoped $\text{YBa}_2\text{Cu}_3\text{O}_{6.6}$ material. We performed elastic PND experiments on three Triple Axis Spectrometers (TAS): 4F1 at Orphée reactor-Saclay, IN22 and Thales et Institut Laue-Langevin-Grenoble, operating at different wavelengths and using different polarization setups (see methods). The TAS were equipped with longitudinal XYZ polarization analysis ($XYZ - PA$), a powerful technique to selectively probe and disentangle the magnetic response from the nuclear one (see supplementary information). The samples were studied either in $(1,0,0)/(0,0,1)$ or $(1,0,0)/(0,1,0)$ scattering planes such as wave-vectors of the form $(H, 0, L)$ or $(H, K, 0)$ were accessible. In the following, the wave-vectors are indexed in reduced lattice units (*r.l.u.*), in units of $(\frac{2\pi}{a}, \frac{2\pi}{b}, \frac{2\pi}{c})$ where a , b and c stand for the lattice parameters of the sample (See Methods for details). We carried out our investigations in two different samples: a twinned YBCO-t sample, same as [10], and a detwinned sample YBCO-d, same as [10, 15], with close compositions (nominal $x=0.6$ and hole-doping $p \sim 0.12$) and critical temperatures ($T_c=61$ and 63 K) but with different oxygen ordering of the CuO chains.

Using $XYZ - PA$, we uncovered a magnetic peak centered at $\mathbf{Q}=(0.5,0,0.5)$ in YBCO-t, as shown by the H-scan along $(H,0,0.5)$ (Fig. 1.b). The magnetic signal can be described by a Gaussian profile, broader than the instrumental resolution. After deconvolution, its intrinsic linewidth (half width at half maximum) is $\Delta_H=0.03 \pm 0.01$ r.l.u. This corresponds to a finite correlation length along the a -axis of $\xi_a = \frac{a}{2\pi\Delta} = \sim 20 \pm 6 \text{ \AA}$, corresponding to ~ 5 planar unit-cells. A rocking scan across $(0.5,0,0.5)$ allowed us to confirm the intrinsic origin of the magnetic signal, excluding extrinsic scattering due to powder line from a parasitic magnetic phase (see supplementary information).

The L -scan of Fig. 1.c was performed in the NSF_X channel and shows a nuclear scattering at $\mathbf{Q}$ -positions of the form $(0.5, 0, L)$ with L integer. This peculiar structure factor is due to the characteristic *Ortho* – *II* structure of the CuO chains, running parallel to the b -axis as represented in Fig. 1.a [35]. The same scan along $(0.5, 0, L)$ direction, obtained using $XYZ - PA$, shows a broad magnetic scattering, at odds with the *Ortho* – *II* oxygen ordering in the CuO chains (Fig. 1.d and supplementary information). This rules out the chains as the host of the new-found magnetic signal rather pointing to the CuO_2 planes (see Fig. 1.a) as the origin of the magnetic response, breaking the LT invariance ($q = 1/2$). The diffuse magnetic signal along the $(0.5, 0, L)$ trajectory of Fig. 1.d further underlines the absence of magnetic correlations along the c -axis.

To ascertain the existence of the $q = 1/2$ magnetism and unravel scattering from CuO chains and CuO_2 planes, we carried further PND investigations in YBCO-d along a few directions in momentum space shown in Fig. 2.e. Fig. 2.a shows a H-scan in the SF_X channel revealing the occurrence of a magnetic peak, centered at $(0.5, 0, 0) \equiv (\pi, 0)$. As in YBCO-t, the signal is at short range with $\Delta_H = 0.025 \pm 0.01$ r.l.u. given by the fit with a Gaussian profile. This corresponds to $\xi_a = \frac{a}{2\pi\Delta} = \sim 24 \pm 4 \text{ \AA}$, which represents correlations over ~ 6 unit cells, consistent with the value deduced in the YBCO-t sample. The amplitude of the total magnetic scattering has been estimated in absolute units after calibration by the intensity of the reference $(1, 0, 0)$ nuclear Bragg peak. The corresponding magnetic intensity is weak and represents only $\sim 0.3 \pm 0.1$ mbarn once integrated in momentum space. This is about 10-15 times lower than the one reported for the long range ordered ($q = 0$) *IUC*-magnetism at the $(1, 0, 0)$ position [10, 12, 14, 15] and explains why the magnetic signal remained hidden in previous experiments. It can be associated with a local magnetic moment of only $\sim 0.02 \mu_B$ assuming a uniform distribution (see supplementary information). The same scan in the NSF_X channel Fig. 2.b reveals two nuclear peaks at $H = 0.385$ and 0.625 , inherent to the *Ortho* – *VIII* oxygen ordering

of the CuO chains [35], in that YBCO-d sample [36], that leads to a nuclear contribution at $q_{Ch} = (H \pm 0.125, 0, 0)$ where no magnetic signal occurs (Fig. 2.a). The absence of magnetic scattering at the characteristic q_{Ch} positions confirms the CuO_2 planes as the origin of the magnetic response at $H = 0.5$.

We further performed a survey of the momentum dependence of the magnetic signal in the detwinned YBCO-d sample, where a and b directions are clearly identified, to determine its planar structure factor. Fig. 2.c shows the resulting magnetic intensity along the $(H, 0.5, 0)$ trajectory, as given by $XYZ - PA$. Interestingly, the H -scan reveals as well a magnetic peak centered at $(0, 0.5, 0) \equiv (0, \pi)$ while no magnetic intensity is seen at $\mathbf{q}_{AF/DDW} = (0.5, 0.5, 0) \equiv (\pi, \pi)$. The associated magnetic pattern is then found along both CuO -bond directions with actually a very similar intensity. That indicates a short range uni-axial (with domains) or bi-axial magnetism leading to a local doubling or quadrupling (2x2) of the unit cell, never reported previously. Additional measurements with the sample aligned within $[a, c]$ plane allowed us to elucidate the L -dependence of the out-of-plane magnetic correlations. Fig. 2.d shows an L -scan across $(0.5, 0, 0)$ in the SF_X channel highlighting a broad magnetic peak, centered at $(0.5, 0, 0)$. The extracted correlation length (from a fit by a Gaussian function) $\xi_c \simeq 13 \pm 1 \text{ \AA}$ is very short and does not exceed ~ 1 unit-cell in the c direction ($\Delta_L = 0.14 \pm 0.01 \text{ r.l.u.}$).

To determine the onset temperature of the short range $q = 1/2$ magnetism, we measured the temperature dependence of the magnetic signal at $(0.5, 0, 0)$ in YBCO-d, both in the SF_X channel and using $XYZ - PA$. Fig. 3.a shows that the scattered magnetic intensity splits into a leading out-of-plane magnetic component I_c displaying an order parameter-like temperature dependence and a subsidiary in-plane magnetic component, I_b , which at variance, remains almost constant as a function of temperature. Our measurements show that the onset temperature for the dominating I_c magnetic component is $T^* \sim 235K$. Fig. 3.b shows the temperature dependence of the magnetic signal at $(0, 0.5, 0)$ as deduced from $XYZ - PA$ analysis. The magnetic

response reproduces the same Ising-like orientation of the magnetic moment, with a similar amplitude as at $(0.5, 0, 0)$, with a major I_c , out-of-plane component arising at $T^* \sim 235K$ and following the same order parameter-like temperature dependence. The H-scans across $(0.5, 0, 0)$ on Figs. 3.c-d show the drop of the magnetic signal from 10 to 300K, respectively. The data correspond to measurements in the $SF_{X,Y,Z}$ channels. Note in Fig. 3.c that the magnetic signal in the X channel corresponds to 6 times the statistical noise related to the background. Further, since there is no atomic Bragg peak to subtract, this experiment is much easier than the earlier experiments [10, 14]. However, the nuclear scattering from the chains oxygen atoms is strong enough to hide the weaker magnetic scattering in an unpolarized neutron experiment.

Importantly, the temperature dependence of out-of-plane magnetic response, I_c , matches the one reported for the *IUC*-magnetism (see supplementary information): I_c sets-in at $T \simeq T^*$, the PG onset temperature as reported from resistivity measurements [37], and of $T \sim T_{mag}$, the onset temperature for the $q = 0$ order [10, 14], suggesting a common origin of both IUC order and short range $q = 1/2$ magnetism reported here. On general grounds, because it breaks LT , the $q = 1/2$ magnetism could be an alternative candidate for the opening of the *PG* state, potentially solving a long-standing question. Along the same line of thought, it could as well play a significant role in the electron Fermi pockets formation [2] yielding a Fermi surface reconstruction known to be exclusively occurring within the *PG* state.

Our comprehensive set of PND data gives a coherent picture for the $q = 1/2$ magnetism occurring at commensurate $(\pi, 0) \equiv (0, \pi)$ in high- T_c superconducting $YBa_2Cu_3O_{6.6}$. First, the location of the observed hidden magnetism is clearly distinct from $q_{AF} \equiv (\pi, \pi)$. This rules out various reported magnetic patterns, namely the *AF* spin order, π -flux phases-like patterns or *DDW* [31, 32], all phases located at the commensurate (π, π) position, or Spin Density Wave (SDW) located at incommensurate position $q_{SDW}=q_{AF} \pm (\delta, 0)$ or $(0, \delta)$ with $\delta \sim 0.1$ revealed by spin fluctuations induced by zinc impurity [38]. Second, the occurrence of both

propagation vectors $\mathbf{q}_1 = (0.5, 0, 0)$ and $\mathbf{q}_2 = (0, 0.5, 0)$ suggests a biaxial ordering with a double- $\mathbf{q}$ antiferromagnetic structure, corresponding to a quadrupling (2x2) of the unit cell. However, uniaxial ordering, doubling the unit cell along each direction of the CuO bonds, can as well account for the observed patterns, assuming equi-populated magnetic domains along each direction. This can happen even in the detwinned sample if the magnetic domains do not depend on the underlying orthorhombic structure. Further, the magnetic moment predominantly observed perpendicular to the CuO_2 layers does not support an interpretation in terms of Cu spins that are locked within the CuO_2 planes owing to their strong XY anisotropy [33]. It instead favors loop current patterns as the ones shown in Fig. 4.a where orbital moments have to be perpendicular to the planes where currents are confined [19].

Following all these observations, one can build real space pictures based on loop currents to account for both IUC order and hidden $q = 1/2$ magnetism. As originally proposed in [39, 40], LCs are conveniently characterized by four degenerate states that can be represented by anapole moments pointing along the four planar unit cell diagonals as displayed in Fig. 4.a where each color corresponds to a given anapole orientation. Interestingly, a simple model composed of 2×2 LCs , covering 4 unit cells, with anapoles turned at 90° at each adjacent unit cell [5] (represented in Fig. 4.b) nicely agrees with the measured structure factor of the $q = 1/2$ magnetism. This anapole-vortex-like state corresponds to the smallest possible domain ($P=1$) of LCs supercell recently proposed to break LT [27]. The pattern is both chiral and P -breaking, and therefore of $mm2$ symmetry as it has been recently reported from photogalvanic experiments [41]. A natural question is then what can be the interplay between both LCs phases with distinct propagation wave-vectors, $q = 0$ and $q = 1/2$? First, the short-range nature of the observed correlations implies 2×2 LCs islands of only about $\sim 20\text{-}25$ Å. This therefore precludes a uniform distribution of 2×2 LCs superposed to LCs that respect LT .

Inhomogeneous pictures in real space should be considered instead, revealing a hidden anap-

olar or magnetic texture. How can a uniform LC order coexist with a modulated one at short range ? This can be accounted for by locating the short range modulated phase at the walls boundaries between the long range uniform ($q = 0$) domains. Along the same line of thought and by analogy with the framework of electronic liquid crystals of coexisting smectic modulations and intra-unit-cell nematicity [42], one can speculate about the coexistence of a "smectic" short-range ($q = 1/2$) 2×2 LCs magnetism with a "nematic" ($q = 0$) longer range magnetism (ferro-anapolar). According to this picture, the observed amplitudes of the $q = 1/2$ magnetism (located at the boundaries separated larger $q = 0$ domains) would determine the volume fraction of both magnetic patterns within the crystal. The observed $\sim 0.3 \text{ mbarn}$ momentum integrated magnetic intensity now implies that one site over four belongs to the 2×2 LCs clusters assuming the same anapole amplitude (and so, the same magnetic moments amplitude) in all unit cells. Real space pictures can be built following these requirements. As an example, Fig. 4.c shows a pattern of anapoles over 20×20 unit cells that represents such a topological arrangement of anapoles (and consequently related loop currents and orbital magnetic moments). Its calculated structure factor matches the observations of both the short range magnetism at both $(0.5, 0, 0)$ and $(0, 0.5, 0)$ and longer range IUC magnetism. This picture can be extended to a larger number of unit cells (for instance with more than one 2×2 LCs cluster) with only two requirements: i) the clusters should be isolated and ii) should represent in total a quarter of the unit cells. The longer range uniform LCs domains are forming the large supercells (of $2P \times 2P$ size) introduced by C.M. Varma [27] to account for the Fermi arcs in the PG state. Note however that the $P=1$ reported here cannot explain the observed Fermi arcs or magneto-oscillations. As shown in supplementary information, the LCs supercells are predominantly characterized in momentum space by a set of satellites magnetic peaks located at $\pm \frac{1}{2P}$ from the atomic Bragg peak positions. As far as $P \gtrsim 10$, they would appear at $q = 0$ due to the limited momentum instrumental resolution of elastic PND experiments [5]. However, more experiments are necessary

to clarify this point. Meanwhile, as far as 1 to 4 site occupation rule holds, 1D arrangements of anapoles either horizontal or vertical as shown in Fig. 4.d-e could as well describe the data, with however an additional constraint of equi-populated domains along both directions. Note that the magnetic texture, through the domains size P , can vary noticeably within the crystal leading to a distribution of satellite peaks near the Bragg peaks with similar short range $q = 1/2$ magnetism. One can therefore envisage a vast range of possible hidden magnetic textures opened by the observation of short range $q = 1/2$ magnetism.

Finally, it is worth recalling that magnetic local probes experiments (Nuclear Magnetic Resonance and muon Spin Rotation) do not observe the expected static local magnetic fields of the magnetism observed in elastic PND measurements [5, 43]. Instead, fluctuating magnetic response in the PG state has been reported by muon spectroscopy[18]. This suggests a magnetic texture slowly fluctuating at a $\sim 10ns$ time scale, encompassing the $q = 0$ IUC response and the short range $q = 1/2$ magnetism. Both appear static in PND owing to the instrumental energy resolution of ~ 0.1 meV. We hope our discovery would motivate further experimental investigations in other cuprate families and other hole-doping levels as well as theoretical investigations to understand the role of the hidden magnetic texture in the phase diagram of High- T_c superconducting cuprates.

Methods

Samples

The PND study was performed on two different samples of same nominal composition $YBa_2Cu_3O_{6.6}$ although they exhibit different oxygen ordering. The twinned sample ($T_c=61K$ and hole-doping $p=0.107$) is the same as the one used in [10] with an Ortho-II oxygen ordering. It has a mass of $\approx 10g$ and a mosaic spread of 1.5° , determined by performing rocking curves about nuclear Bragg peaks. The twin-free sample has been obtained by methods described in [36] ($T_c=64K$

and hole-doping $p=0.115$). It consists of co-mounted single crystal plates of about ($20 \times 20 \text{ mm}^2$) and exhibits an Ortho-VIII oxygen ordering. The total sample mass is $\approx 2\text{g}$ and the measured mosaic spread is 2° . We used pseudo-tetragonal notations for the twinned sample, with $a = b = 3.85\text{\AA}$ and $c = 11.75\text{\AA}$. The lattice parameters of the twin-free sample are $a = 3.88\text{\AA}$, $b = 3.82\text{\AA}$ and $c = 11.75\text{\AA}$.

Polarized neutron diffraction

The PND experiments were carried out on three instruments: the triple axis spectrometer (TAS) 4F1 (Orphée reactor, Saclay) and the IN22 and Thales TASs (Institut Laue Langevin, Grenoble), which are described in more details in the Supplementary Materials 1. These instruments are equipped with distinct neutron polarization set-ups and were operating with three distinct neutron wavelengths, to guarantee the reproducibility of the measurements. We used incident neutron wave-vectors of $\mathbf{k}_i = 2.57\text{\AA}^{-1}$ on 4F1, $\mathbf{k}_i = 2.662\text{\AA}^{-1}$ on IN22, and $\mathbf{k}_i = 1.5\text{\AA}^{-1}$ on Thales. As detailed in the figures caption, the samples were either aligned in the $(1,0,0)/(0,0,1)$ or $(1,0,0)/(0,1,0)$ scattering planes, so that wave-vectors $\mathbf{Q}$ of the form $(H, 0, L)$ or $(H, K, 0)$ were accessible, respectively. H, K or L-scans were performed across positions of the form $(0.5, 0, 0)$ or $(0, 0.5, 0)$ in r.l.u. Both SF and NSF scans were done in order to crosscheck the absence of nuclear scattering at magnetic positions. The longitudinal $XYZ - PA$ was performed using:

- MuPad spherical polarization analysis device with zero field at sample chamber on 4F1, for the twin-free $YBa_2Cu_3O_{6.6}$ sample. The incoming and outgoing beam polarizations are realized using Bender supermirrors.
- CRYOPAD spherical polarization analysis device with zero field sample chamber on IN22 and Thales for the twin-free $YBa_2Cu_3O_{6.6}$ sample. The incoming and outgoing beam polarizations are realized using Heusler crystals.

Data availability

The data obtained on IN22 at ILL are available at <https://doi.org/10.5291/ILL-DATA.CRG-2776>. The data obtained on Thales at ILL are available at <https://doi.org/10.5291/ILL-DATA.4-02-600>. The rest of the data that support the findings of this study is available from the corresponding authors upon request.

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Acknowledgments

We thank C. Pépin and Y. Zaanen for stimulating discussions. We thank C.M Varma for bringing to us the illuminating perspectives of loop currents supercells. We acknowledge supports from the project NirvAna (contract ANR-14-OHRI-0010) of the French Agence Nationale de la Recherche (ANR) and from the GenLoop project of the LabEX PALM (contract ANR-10-LABX-0039-PALM).

Author Information

Contributions

Y.S. and P.B. conceived and supervised the project; D.B., Y.S. and P.B. performed the experiments at LLB Saclay; D.B., V.B. and L.M.-T. performed the experiments at ILL Grenoble; F.B., M.B. and P.S. were the instrument local contacts and ILL. D.B. and P.B. analyzed the neutron data; T.L. synthesized the single crystal samples; D.B., Y.S. and P.B. wrote the manuscript with further contributions from all authors. All authors contributed to this work, read the manuscript and agree to its contents.

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Ethics declarations

Competing interests

The authors declare no competing interests.

Fig. 1: Novel commensurate magnetism in twinned $YBa_2Cu_3O_{6.6}$ (YBCO-t) : (a) Crystal structure of $YBa_2Cu_3O_{6+x}$ with the CuO chains running along the b-axis (gray shaded arrow) and the CuO_2 planes represented by the pink shading. (b) H-scan across (0.5,0,0.5) showing magnetic scattering extracted from XYZ-PA. The magnetic scattering is fitted by a Gaussian line centered at (0.5,0,0.5). (c) Background subtracted L-scan along the (0.5,0,L) direction in the non-spin flip (NSF_X) channel. The peaks in the (NSF_X) channel correspond to nuclear scattering from the Ortho-II oxygen chains superstructure. (d) Q-dependence of the magnetic intensity along the (0.5,0,L) trajectory as extracted from full XYZ-PA in YBCO-t. Data in (b-d) were measured on TAS-4F1 at 80K with the sample aligned in the (1,0,0)/(0,0,1) scattering plane. Lines are fits to the data. Error bars represent one standard deviation. Raw data are given in supplementary information.

Fig. 2: Biaxial planar short ranged magnetism in twin-free $YBa_2Cu_3O_{6.6}$ (YBCO-d): (a) Background subtracted H-scan across $(0.5,0,0)$ in the Spin Flip (SF_X) channel. The magnetic intensity appears as a Gaussian signal centered at $(0.5,0,0)$. (b) Background subtracted H-scan along $(H,0,0)$ in the Non Spin Flip (NSF_X) channel showing the background subtracted nuclear scattering from the (Ortho-VIII) type chains superstructure. (c) H-scan across the $(H,0.5,0)$ showing a magnetic signal centered at $H = 0$. (d) Background subtracted L-scan across $(0.5,0,0)$ in the spin-flip (SF_X) channel. The magnetic intensity appears as a Gaussian signal centered at $(0.5,0,0)$. (e) 3D representation of the reciprocal space showing the momentum scans performed in (a-d). Data in (a-b,d) were measured on IN22 at 1.6K with the sample aligned in the $(1,0,0)/(0,0,1)$ scattering plane. Data in (c) were measured on 4F1 at 4K with the sample aligned in the $(1,0,0)/(0,1,0)$ scattering plane. Lines are fits to the data. Error bars represent one standard deviation. Raw data are given in supplementary information.

Fig. 3: Temperature dependence of the biaxial magnetism in detwinned $YBa_2Cu_3O_{6.6}$ (YBCO-d): Temperature dependencies of the magnetic intensities measured at **(a)** $(0.5,0,0)$ as extracted from $XYZ - PA$ (dark blue circles) and background subtracted SF_X data (light blue circles), and **(b)** $(0,0.5,0)$ as extracted from $XYZ - PA$. I_c is the out-of-plane response whereas the in-plane magnetic scattering I_b in panel (a) (I_a in panel (b)) corresponds to the green symbols. The blue symbols correspond to the sum $I_c + I_b$ or $I_c + I_a$ in panels (a) and (b) respectively. The weaker in-plane contributions are found of the same amplitude such that $I_a = I_b$. H-scans across $(0.5,0,0)$ measured in the Spin Flip ($SF_{X,Y,Z}$) channels at **(c)** 10K and **(d)** 300K. The magnetic intensity appears as a Gaussian signal centered at 10K and drops at 300K in YBCO-d. Data in **(a, c-d)** were measured on *Thales* with the sample aligned in the $(1,0,0)/(0,0,1)$ scattering plane. Data in **(b)** were measured on *4F1* with the sample aligned in the $(1,0,0)/(0,1,0)$ scattering plane. Raw data of **(a,b)** are given in supplementary information.

Fig. 4: Hidden magnetic texture from modelization of $q = 1/2$ short range and IUC magnetism observed in PND. (a) Four possible degenerate ground states of loop currents [39, 19, 40]. The grey and purple arrows represent magnetic moments along the c axis whereas the four other arrows represent anapoles of each of the four states. (b) 2x2 loop currents pattern, corresponding to $P=1$ in [27], that can account for the $q = 1/2$ short range magnetic signal reported here. The currents are circulating clockwise (in grey) and anti-clockwise (in purple). The four states are represented by anapoles undergoing a 90° rotation between adjacent domains. (c) Example of 2D magnetic texture with 20x20 unit cells paved by anapoles (LCs states). The central cluster with 2x2 LC patterns describe the $q = 1/2$ short range magnetism whereas the IUC magnetic signal arises from the larger color domains. (d,e) Similar LCs construction for horizontal and vertical 1D domains. In panels (c-e), only anapoles are represented having the four possible orientations.

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