Experimental report

01/06/2016

Proposal: **4-03-1714**

Council: 10/2014

Title: Fingerprint of unconventional charge instabilities in the normal state spin excitation spectrum of superconducting cuprates

Research area: Physics

This proposal is a new proposal

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Samples: $YBa_2Cu_3O_{6.6}$

Instrument	Requested days	Allocated days	From	To
IN20 CPA	7	6	06/07/2015	13/07/2015

Abstract:

Using spin-polarized neutrons, we propose to determine accurately the T-regimes in which the spin excitation spectrum exhibits marked changes in superconducting $YBa_2Cu_3O_{6.6}$. In such a sample, several electronic instabilities occur : (i) an intra-unit-cell magnetic order upon entering the mysterious pseudo-gap phase at $T^* \sim 250$ K, (ii) an incipient charge density wave state at $T_{cdw} \sim 150$ K, (iii) a d-wave SC state at $T_c = 62$ K. While experimentalists agree on the main features characterizing the renormalization of the spin excitation spectrum upon entering the superconducting state, there is still a large discrepancy among different unpolarized INS studies concerning the exact evolution of the spin excitation spectrum in the normal state. To a large extent, this is due to the difficulty to accurately remove the nuclear background at high temperature. This problem can be overcome by a more extensive use of spin-polarized neutrons.

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Fingerprint of unconventional charge instabilities in the normal state spin excitation spectrum of superconducting cuprates

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Introduction:

Over the last decade, the studies of anomalous electronic properties of superconducting cuprates have been widely focused on the mysterious nature of the so-called pseudo-gap (PG) phase out of which the *d-wave* superconducting (SC) dome emerges (Fig. 1). Indeed, the understanding of the intrinsic nature of the PG phase should provide condensed physicist with the key parameters involved in the SC pairing at lower temperature. Recently, a new set of experimental observations had a deep impact on the way one may understand the PG state. Resonant ultra sound measurements point out that the PG phase is a true symmetry breaking state [1] (♦In Fig. 1), and superconductivity is likely to develop around the quantum critical point associated with this new state of matter. Spin-polarized neutron diffraction measurements reveal the appearance of an intra-unit cell (IUC) magnetic order at T*, the PG temperature [2] (● in Fig. 1). This IUC order exhibits the same symmetry properties as a loop current (LC) state [3] or spin nematic state [4]. At lower temperature (● in Fig. 1), X-ray measurements highlight the existence of an incipient charge density wave (CDW) state [5], that (i) competes with the SC state and (ii) can be further stabilized under magnetic field at the expense of the SC state. While the previous studies in cuprates have mainly focused on Cu orbitals, these new observations suggest that the importance of the O orbitals has been widely underestimated.

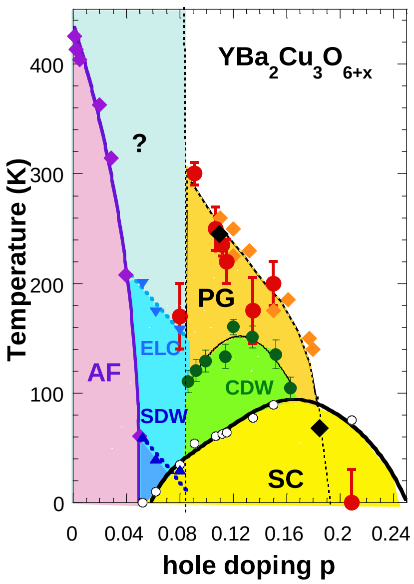

Fig.1: $YBa_2Cu_3O_{6+x}$ phase diagram as a function of the hole doping (p) showing the *d-wave* superconducting state (SC), an incipient chage density wave phase (CDW) and the pseudo-gap phase (PG). The lines and colored area are guides to the eyes

Based on these observations, new scenarios for the PG states are emerging. Among them one can quote: (A) IUC instabilities (spin or charge nematic states [6] or LC phase [3]), (B) a composite order parameter state, mixing *d-wave* superconductivity and *d-wave* charge orders [7], (C) intertwined charge/current density wave states [8], (D) pair density wave states bound to certain IUC orders[4,9]. Whatever the model which is considered, one may expected distinct fingerprints in the two particle correlation functions, such as in the charge susceptibility probed directly by electronic Raman scattering or indirectly by IXS or INS (through the renormalization of the phonon spectra), or in the spin susceptibility probed by INS.

Experimental results:

On IN20, we carried out a study to determine accurately the T-regimes in which the spin excitation spectrum exhibits marked changes in $YBa_2Cu_3O_{6.55}$ (p=0.11 – T_c=58 K). For such a system, the IUC magnetic order take place at T*~250 K. The CDW order starts around T_{cdw} ~150 K according to X-ray measurements. The sample is made of small high-quality single crystals, co-aligned on Al plates. The AF magnetic resonance peak has already been identified at ~34 meV. The sample was aligned in the scattering that allows the study of odd spin fluctuations around $\mathbf{Q}_{AF}$= (0.5,0.5,1.7) (see fig.2). Using CRYOPAD, the magnetic scattering in the spin flip channel (SF) was measured at 3 distinct energy transfers {34;21;9} meV. Results are reported and described in Fig. 3-5. The main outcome of our study is that the PG state is primarily responsible of the modification the spin excitation spectrum in the normal state. The incipient CDW order that develops below ~150 K appears as a subsidiary effect, whose impact (if any) on the spin excitation spectrum should remain rather weak. This study confirms that the normal state spin dynamics is essentially controlled by the physics of the PG.

Our polarized neutron scattering data should be further compared with the study of the spin excitation dispersion and a-b anisotropy performed in addition on thermal TAS on Puma at FRM-II (no reported here). The whole set of data collected on different TAS will provide stringent constraints on models developed to account for PG physics.

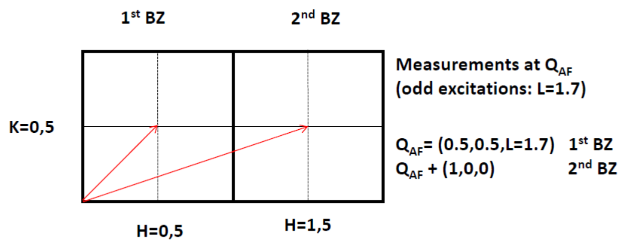

Fig.2: scattering geometry

Notations:

SFx = full spin flip signal
2X-Y-Z = pur magnetic signal
X –Z = 1st part of the magnetic signal
X – Y = 2nd part of the magnetic signal
Y+Z –X = background

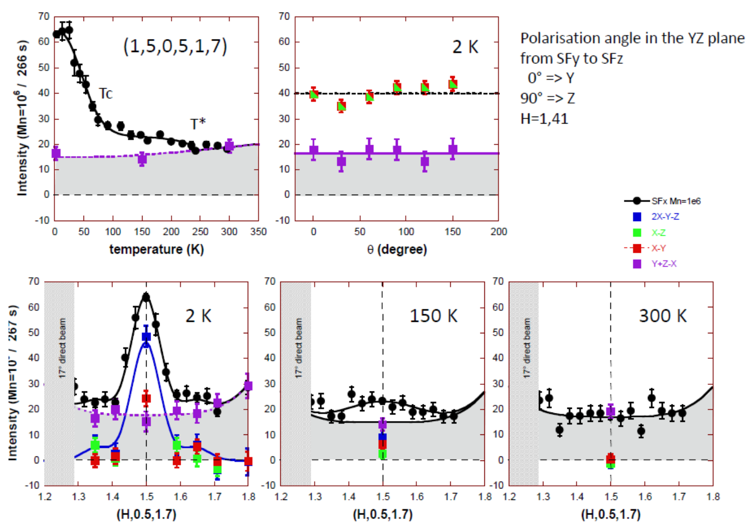

Fig.3: measurements at 34 meV

The T-dependence of the magnetic scattering at 34 meV displays a marked change at T_c, characterizing the appearance of the so-called magnetic resonance peak in the SC state. In the normal state, spin fluctuations start being sizeable below T*, the onset of the PG state. Spin fluctuations do not exhibit any kind of spin anisotropy. The constant E-scans reveal the existence of tail around that resonance peak at $\mathbf{Q}_{AF}$, whose survive in the normal state

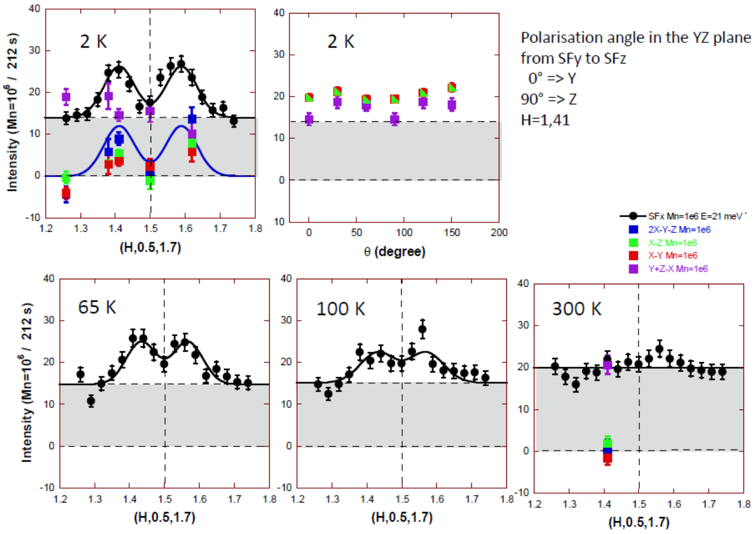

Fig.3: measurements at 21 meV

At this energy, the spin excitation spectrum is characterized by resonant collect excitations that disperse downward from the resonance peak in the SC state. Net incommensuarate spin fluctuations are observed in the SC state. Above Tc, incommensurate spin fluctuations survive, but at 100 K, they could be connected either with incipend CDW correlation or the PG state.

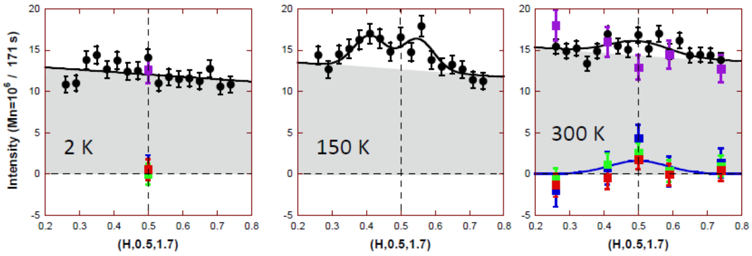

Fig.4: measurements at 9 meV

At this energy, the spin excitation spectrum in the SC state display a net spin gap, that is progressively filled in the normal state. The observation of well-defined incommensurate spin fluctuations in the normal at temperature where CDW correlations are still very weak, suggest the PG state is mainly responsible for their appearance,

References:

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