Experimental Report

06/02/2014

Proposal: **4-01-1209** **Council:** 4/2012

Title: Spin Fluctuations in Underdoped High Temperature Superconductor HgBa2CuO4+d

This proposal is a new proposal

Researh Area: Physics

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Samples: HgBa2CuO4

Instrument	Req. Days	All. Days	From	To
IN8	10	10	16/11/2012	26/11/2012

Abstract:

One of the central issues in the cuprates is to clarify the interplay between magnetism and superconductivity. Intensive efforts have been devoted toward the magnetic resonance and the seemingly universal hourglass-like magnetic dispersion near the antiferromagnetic wave-vector (QAF). Our recent neutron scattering work on HgBa2CuO4 (Hg1201) has revealed two novel magnetic excitations in the pseudogap state. Unlike the more conventional magnetic excitations, these excitations are nearly dispersionless and exist throughout the entire Brillouin zone. The hourglass dispersion has yet to be conclusively observed in Hg1201. Initial results on new very underdoped sample(Tc=50K) show a resonance at 32 meV and hints of an ‘hourglass’-like dispersion emanating from that point. Here we propose to further study our underdoped Hg1201 sample to firmly establish the existence and properties of the hourglass dispersion in Hg1201. We will also search for the pseudogap state novel excitations in this very underdoped Hg1201 sample.

Spin Fluctuations in Underdoped High Temperature Superconductor $HgBa_2CuO_{4+\delta}$

The relationship between magnetic fluctuations and superconductivity is one of the most important prevailing issues concerning the physics of the cuprates. Neutron scattering studies of several hole- doped compounds have revealed a seemingly universal hourglass magnetic dispersion near the antiferromagnetic (AF) wave vector $\mathbf{Q}_{AF}$ [1]. A related and widely discussed feature is the magnetic resonance, a collective spin-1 excitation in the superconducting state with well-defined energy at the 'neck' of the hourglass [2]. In our recent work at ILL on $HgBa_2CuO_{4+\delta}$ (Hg1201), the compound with the highest Tc among single-layer cuprates, we discovered novel Ising-like excitations [3] that appear to be related to the previously observed lattice translational symmetry preserving ($\mathbf{q}$ = 0) pseudogap magnetic order [4,5]. The characteristic energies of these Ising-like excitations appear to coincide with the peak in AF fluctuations, thus suggesting a connection between the two. The proposed experiment was to study a more underdoped Hg1201 sample to firmly establish the existence and properties of the hourglass dispersion in Hg1201. We will also search for the pseudogap state novel excitations in this

A new sample with T_c=55K, and mass of ~ 1.6g labeled UD55 was prepared for this experiment. The sample was mounted in the (HHL) scattering plane. Measurements were performed in a high-resolution configuration (δE≈5 meV at 50 meV energy transfer): Cu(200) monochromator and PG(002) analyzer with fixed k_f = 3.84 $Å^{-1}$. One PG filter was used on k_f. The cryofour high temperature furnace was used.

We first investigated the possible presence of the Ising-like dispersionless modes, which are mostly easily identified in temperature-difference plots. Figure 1a shows energy scans at various $\mathbf{Q}$ at 2K ($T<<T_c$) and 355K (T*≈410 K). The corresponding I(2K)-I(355K) plots in (b) reveal a rather surprising result. Two peaks corresponding at 54 meV and 44 meV are visible. The 54 meV peak is the same energy as the higher energy Ising-like mode identified at higher doping levels:UD65 and OP95[3]. This mode energy therefore appears to be doping independent. The energy 44 meV is consistent with prior results showing a hardening of the lower-mode energy upon underdoping (32 meV in OP95 and 39 meV in UD65). However, contrary to prior results in OP95, both modes are weakest at small in-plane $\mathbf{Q}$ and becomes increasingly intense at large momenta. This would seem to run counter to the expected dependence if they due to magnetism. Comparing to measurements in OP95 under the same experimental conditions, the higher energy mode in UD55 is ~3-4 times weaker while the lower energy mode is ~3-4 times stronger. Note that this is a rough estimate since as described above the $\mathbf{Q}$ dependence is different between the two samples. A proper determination of the total spectral weights would require knowledge of the form/structure actor, which are currently not known. Nevertheless, it seems that the lower energy mode becomes stronger at the expense of the higher energy mode with underdoping. Figure 2 shows the temperature dependence of the Ising-like modes relative to the pseudogap temperature T*≈410K. It is difficult to fit the data accurately due to uncertainties in the background shape and its temperature dependence. Nevertheless, there is a qualitative decrease of both mode intensities upon approaching T*, consistent with prior results at higher doping.

In the next part of the experiment, we focused on uncovering the antiferromagnetic fluctuations. Fig. 3 shows energy scans at the in-plane antiferromagnetic wavevector $T<<T_c$

and T=T_c+10K. The temperature difference reveals a possible resonance peak centered at 30 meV. However, as can be seen in the raw data, this resonance mode sits on-top of a large phonon peak. In this, and subsequent experiments we found that we could not avoid this phonon by changing the c-axis momentum transfer, as such, despite numerous attempts with unpolarized neutrons, we were unable to obtain more detailed measurements of the magnetic response, (e.g. **Q** scans), at this energy. Future experiments utilizing polarized neutrons is highly desirable to study this energy and a possible resonance there further.

AF fluctuations are better studied with constant energy scans. Fig. 4 shows such scans at many energies. Care was taken to avoid phonon contamination in these scans. From the fitted amplitude shown in Fig. 4b, the net magnetic scattering at 2K is small at 20 meV, peaks at about 40 meV and is suppressed slightly at higher energies. Interestingly at T=355K, the AF fluctuations below ~55meV are suppressed. This is consistent with results in prior cuprates showing a decrease of low energy AF fluctuations upon approaching T* [6].

In summary we have discovered Ising-like modes in the more underdoped regime of Hg1201. The energies of these modes are consistent with the trend inferred from prior measurements in two more highly doped samples. However, the momentum dependence of these modes seems to have changed drastically. Additionally we have measured the AF fluctuations and found a strong suppression of low energy intensity upon approaching the pseudogap temperature.

References:

[1]J. R. Schrieffer, Handbook of high-temperature superconductivity, Springer (2007).
[2] N. B. Christensen et al. Phys. Rev. Lett. 93, 147002 (2004); M. Fujita et al., Phys. Rev. B 70, 104517 (2004). [3] Y. Li *et al.*, Nature **468** 283 (2010); Y. Li *et al.*, Nature Phys. **8**, 404 (2012). [4] B. Fauqué *et al.*, Phys. Rev. Lett. **96**, 197001 (2006);Y. Li *et al.*, Nature **455**, 372 (2008); Y. Li *et al.*, Phys. Rev. B 84, 224508 (2011). [5] Varma, C. M. Phys. Rev. B **55**, 14554 (1997). [6] V, Hinkov *et al.* Nat. Phys. **3**, 780 (2007); O. J. Lipscombe *et al.*, Phys. Rev. Lett., **102**, 167002 (2009).

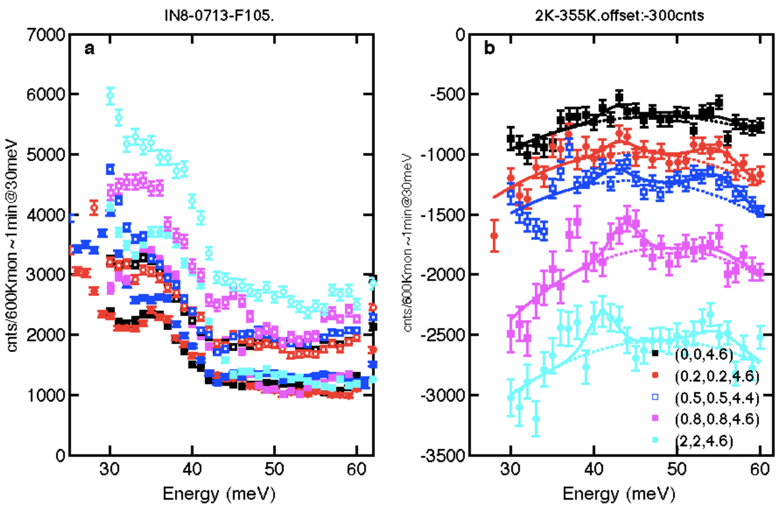

Figure 1 (a) Raw energy scans at various Q. The open symbols are 355K data and the closed symbols are 2K data. Symbol colors are matched to those in the legend of (b). (b)Temperature difference intensity I(2K)-I(350K). Two peaks are revealed

centered at approximately 44 meV and 54 meV. We believe that the apparent peak at 38 meV is due to a softening phonon mode. A similar effect is observed at all dopings of Hg1201, Data are shifted for clarity. The solid lines are fits to two Gaussian peaks with a 2-nd order polynomial background (dotted lines).

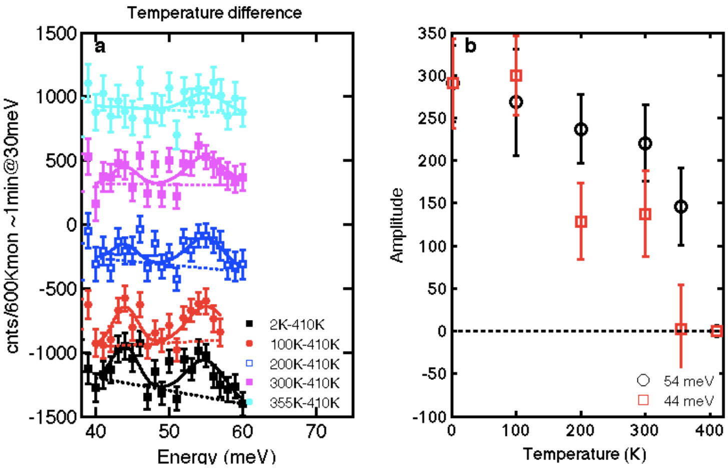

Figure 2. (a) Temperature difference data at **Q**=(0.8, 0.8, 4.6). Data are shifted for clarity. The solid lines are fits to two Gaussian peaks with a 2^{nd} order polynomial background (dotted lines). (b) Temperature dependence of the fitted amplitudes for the two Ising-like modes. This represents the net intensity relative to 410K.

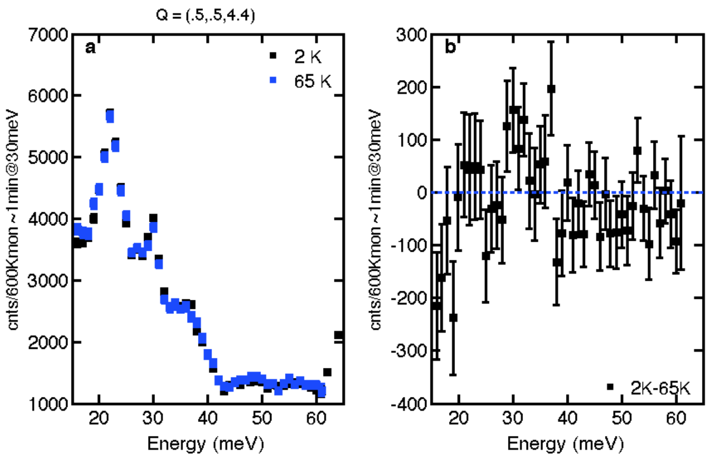

Figure 3 (a) Raw data of energy scans at the 2D antiferromagnetic wavevector **Q**=(.5,.5,4.4) below and above T_c. (b) Change of intensity across T_c at $\mathbf{Q}_{AF}$. There is a possible resonance, indicated by positive signal, at approximately 30 meV.

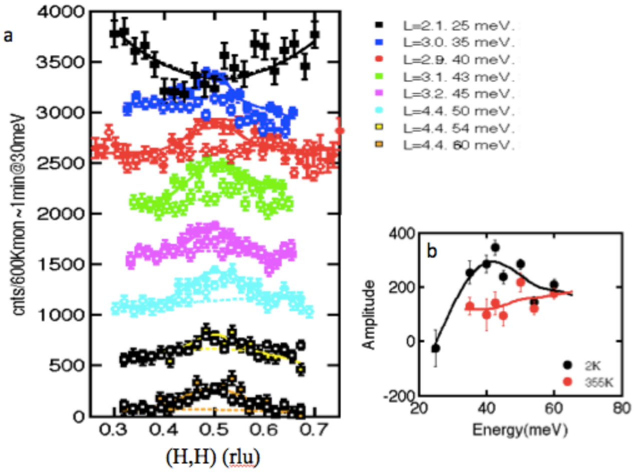

Figure 4 (a) Constant energy scans across the antiferromagnetic wave-vector. The out-of-plane wave-vector L was varied to avoid phonon contamination. Closed symbols are at 2K. Open symbols are at 355K. Data are shifted for clarity. (b) Summary of fitted net intensity at 2K and 355 K. Solid lines are guides to the eye.