Measurement of Magnetic Excitations in x = 0.05 and 0.095 Samples of $La_{2-x}Ba_xCuO_4$

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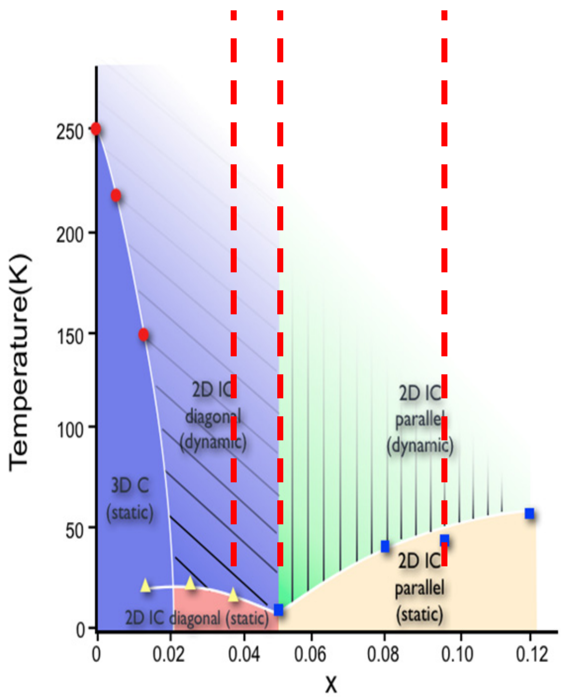
We report on a series of experiments performed on C5 and begun in October-November 2011. The previous study looked at magnetic and lattice excitations for a sample of $La_{2-x}Ba_xCuO_4$ (LBCO) with x = 0.035. The present study continued this series of measurements to samples with x = 0.05 and 0.095. As shown in Fig 1, which displays a magnetic phase diagram for this system that is motivated solely by neutron magnetic order parameter measurements, this series of measurements span many of the interesting regimes of the phase diagram.



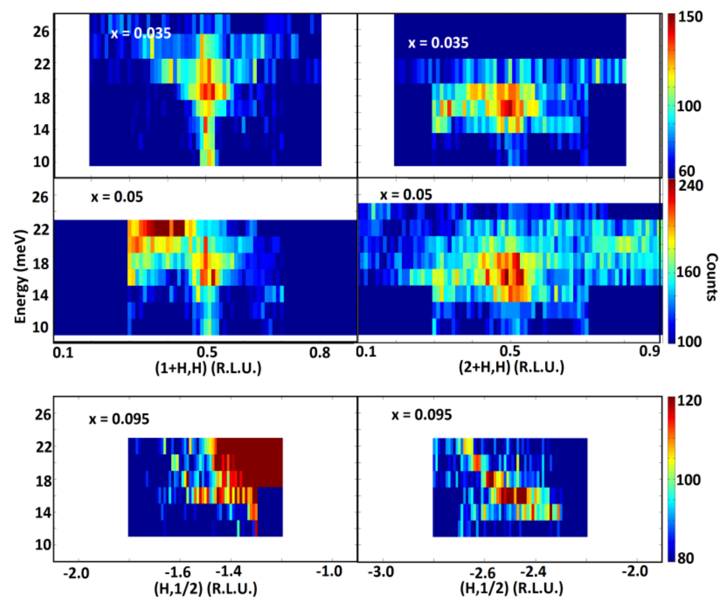


Fig 1 (left): Magnetic phase diagram motivated by neutron order parameter measurements. Starting from x = 0, a three dimensional commensurate antiferromagnetic state (3D C) evolves to coexist with a two dimensional incommensurate antiferromagnetic state that orders along the direction of next nearest neighbor copper atoms in the tetragonal cell (2D IC Diagonal). As x increases, the 3D C is destroyed, while the 2D IC Diagonal persists, eventually rotating to become 2D IC parallel. That is, the ordered state orders parallel to nearest neighbor copper atoms in the tetragonal cell. 2D IC fluctuations, which orient in the same direction as the static 2D IC, pervade the phase diagram for all temperatures measured. Dashed lines indicate samples measured in this series of C5 experiments.

Fig 2 (right): Contour maps of raw data collected from all three C5 experiments. Top two rows show T = 3.2 K, while the bottom row shows T = 3.2 + 35 K data for LBCO x = 0.035, 0.05 and 0.095 samples respectively.

Fig 2 show contour maps of the raw data collected in all three C5 experiments. The panels have been organized so that the left columns shows data for the (3/2, 1/2) magnetic peak position and the right column shows data at the (5/2, 1/2) magnetic peak position. The data is also organized so that the top row shows data for x = 0.035, the middle row shows data for x = 0.05 and the bottom row shows data for x = 0.095. All data is shown for T = 3.2 K, except the x = 0.095 data set which shows the sum of data taken at T = 3.2 K and at T=35 K. The reason for this will be discussed later. All measurements were collected in the same cryostat under identical experimental conditions, with all intensities normalized to their respective monitors. The data in the $x = 0.035$ and 0.05 maps show scans along equivalent <HH> directions, while the $x = 0.095$ maps involve scans along <H>. This reflects the fact that the orientation of the incommensuration of the magnetic signal rotates 45 degrees for $x > 0.05$ relative to $x < 0.05$.

All three experiments show the same qualitative trend to the data. That is, the scattered intensity decreases as a function of energy out to 12 meV. Then, starting at 14 meV there is an enhancement of the scattered intensity. Interestingly, at the (3/2, 1/2) position, this enhancement peaks at around 18 meV, while at the (5/2, 1/2) position, the enhancement peaks at 16 meV. As well, the relative enhancement of the scattering at (5/2, 1/2) is stronger. This observation continues a trend from previous measurements of these samples using SEQUOIA at Oak Ridge National Labs. It was found that the relative enhancement of the scattered intensity at (1/2, 1/2) was less than that at (3/2, 1/2). This is shown in Fig 3.

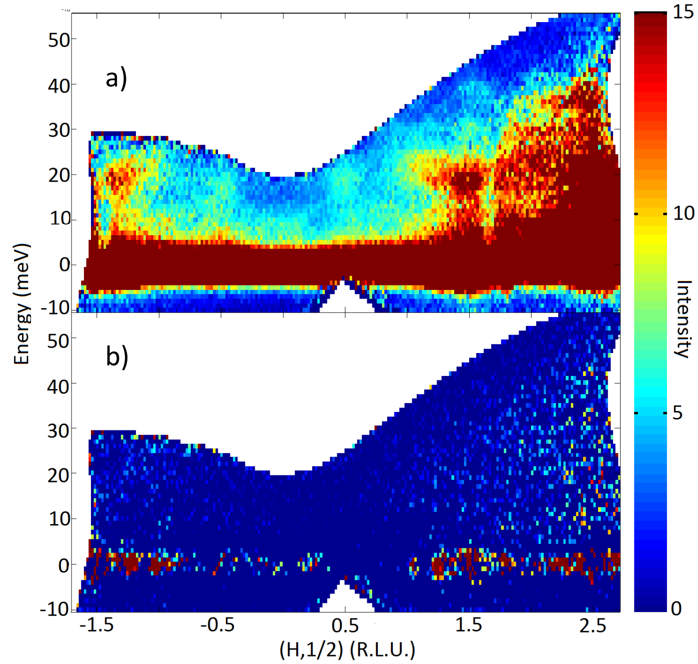


Fig 3: a) Raw data from a SEQUOIA measurement of LBCO $x = 0.095$ at $T = 6$ K. At this temperature, the sample is superconducting. Data has had an integration over all L. Note that this data set has a clean view of (3/2, 1/2) and both (1/2, 1/2) and (-1/2, 1/2), demonstrating the large relative enhancement of the scattering at (3/2, 1/2) as compared to either (±1/2, 1/2). b) A subtraction of the $T = 6$ K and $T = 50$ K data sets from the same experiment. Both data sets have the same integrations as in a). Since T_c for this sample is ~28 K, this plot shows the differences in the scattering between the superconducting and normal state for this material. This result suggests that there is no difference in the inelastic scattering caused by superconductivity for this sample. A similar difference map for the present C5 data on this material yields the same result.

Measurements of the scattering at temperatures both above and below the superconducting transition in the $x = 0.095$ sample, $T_c \sim 28$ K, were also performed. Since for $E \geq 10$ meV the effects of thermal population are negligible when $T \leq 35$ K, we could directly subtract the raw data sets collected at $T = 3.2$ K and 35 K. The result of this analysis is that there was no observable difference between the scattering at these two temperatures in this experiment. This is consistent with our results from a similar analysis of time of flight measurements on this sample, which is shown in Fig 3. We therefore believe there is no difference in the scattering due to superconductivity. This is why in Fig 2 we add the 3.2 and 35 K data sets together, effectively doubling the counting statistics of our measurements of this material.

Our data strongly suggest that this 16-18 meV phenomenon exists independently from the high temperature superconductivity of this system. This idea is supported by: 1) the qualitative trend in the data appears to be independent of Ba concentration, x, and 2) the onset of superconductivity does not affect the inelastic scattered intensity. These results are both consistent with findings from our previous measurements of these samples on SEQUOIA. Moreover, our data have revealed an enigmatic trend. Typically, as $|\mathbf{Q}|$ increases, one expects the scattered intensity to decrease. It is therefore unexpected that the relative enhanced strength of the scattered intensity near 16-18 meV appears to increase with $|\mathbf{Q}|$. Further analysis of the data as well as further experiments to explore this phenomenon in greater detail are ongoing.