Quantum Materials

Polarized neutron scattering study of spin fluctuations in $La_{2-x}Sr_xCu_{1-y}Zn_yO_4$ (x=0.25, y=0.02)

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Within the monolayer cuprate system $La_{2-x}Sr_xCuO_4$ (LSCO), introducing charge carriers to the CuO_2 planes not only rapidly suppresses long-range AF order but also facilitates the formation of a spin density wave (SDW) state in concentrations exhibiting a superconducting phase [1,2]. This state manifests itself experimentally as a quartet of incommensurate peaks distributed at **Q** = (0.5±δ , 0.5±δ) about the undoped compound's AF ordering wave vector [3]. The SDW order is quasi two-dimensional with long range order occurring only within the CuO_2 planes and has been interpreted by many as an indication of the establishment of a state of one-dimensional, self-organized rivers of charge/spin known as "stripes" [1,3].

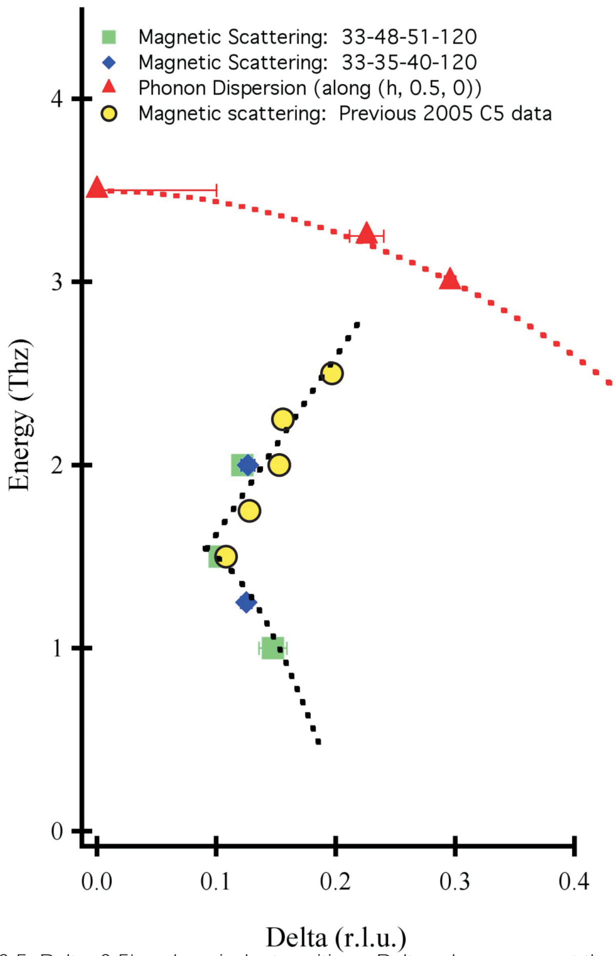
One particularly effective way of probing the relationship between the spin behavior in the cuprates and the high-T_c superconducting phase is realized through the study of the evolution of the magnetic response in cuprate systems whose superconducting phase has been suppressed via Zn-substitution. Nonmagnetic Zn^{2+} substitutes into a Cu^{2+}-site in CuO_2 planes and rapidly suppresses T_c with only a few percent Zn-substitution resulting in the complete elimination of the superconducting phase. Introducing the nonmagnetic Zn-impurities into the CuO_2-planes of the cuprates is theorized to induce a halo of localized Cu^{2+} spins about the impurity site. The regions about these localized Cu^{2+} sites form nonsuperconducting islands that disrupt the coherence of the superconducting phase and suppress T_c in a picture known as the "swiss cheese" model [4]. The Zn-induced suppression of superconductivity however is also accompanied by an anomalous modification and enhancement in the magnetic response in $La_{2-x}Sr_xCu_{1-y}Zn_yO_4$ (LSCZO). Specifically, experiments on Zn substituted, highly overdoped LSZCO(x=0.25, y=0.01) samples have demonstrated that the effect of Zn doping into LSZCO is simply to enhance the severely damped incommensurate magnetic scattering observed in Zn-free overdoped LSCO [5]. The characteristic energy scale in the local susceptibility of Zn-free LSCO(x=0.25) and Zn-doped LSZCO(x=0.25, y=0.01) remained identical in strong contrast to the subgap behavior reported for Zn doping into the LSZCO(x=0.15, y=0.01) system [6].

In our initial studies of overdoped LSZCO, we have uncovered [7] a striking modification to the spin dynamics in the LSCZO(x=0.25, y=0.02) system doped toward the edge of the superconducting dome. In contrast to the nearly dispersionless spin response at low energies observed in the incommensurate spin fluctuation spectrum of LSCO(x=0.25), the Zn-doped LSCZO(x=0.25, y=0.02) system exhibits an anomalous saddle-point-like dispersion as illustrated in Fig. 1. The spin fluctuations in this system disperse inward with increasing energy and reach a minimum at an energy strongly renormalized from that observed in optimally-doped Zn-free LSCO(x=0.165) (T_c ~ 39K) [8]. Instead of a saddle-point minimum occurring at the resonance energy of E_R ~ 40meV in LSCO(x=0.165), the minimum δ now appears at ~ 6meV in this Zn-doped LSCO system, and this drastically reduced energy scale is potentially reflective of the substantially reduced T_c in the Zn-doped variant (T_c ~ 11K) [3]. The precise relation between this renormalized dispersion in LSCZO(x=0.25, y=0.02) and the superconducting phase remains unresolved; however, in addition to this low energy feature, anomalous, dispersive high-energy fluctuations appeared at larger incommensurabilities of δ ~ 0.2 and at energies E > 30 meV. Given the proximity of this signal to known phonon modes, polarized neutron measurements were required to resolve the fundamental origin of the additional fluctuations.

Our polarized neutron measurements on C5 were performed on the identical LSCZO(x=0.25, y=0.02) samples previously studied with the samples aligned within the [HK0] plane. Heusler alloy monochromater and analyzer crystals were used in conjunction with k_i and k_f spin flippers in order to measure the (++), (+-), (-+), and (- -) scattering cross sections. Relatively loose collimations were used with [open, open, 51', 144']. One graphite filter was used on the scattered side to suppress higher order neutrons. A guide-field was applied at the sample position both vertically (out of the scattering plane) and horizontally (along the scattering wave vector) in order to isolate the individual magnetic and nonmagnetic scattering processes. For each field configuration at the sample position, the sample was first warmed to 30 K and then field-cooled to low temperatures to prevent any possible depolarization from trapped flux in the Meissner state.

Our initial results from this investigation suggest a complex mixture of both magnetic and nonmagnetic scattering processes within the higher energy spin fluctuations resolved at the quartet of incommensurate positions above 30 meV. Due to small intensity in the polarized configuration, the precise ratio of nonmagnetic and magnetic scattering was not able to be determined, and the problem is a topic of ongoing study.

Future experiments at E>30meV with substantially increased sample mass will help better resolve the intrinsic nature of the seemingly mixed magnetoelastic modes in this Zn-doped cuprate.



(0.5±Delta, 0.5) and equivalent positions. Delta values represent the average displacement of the four incommensurate spin excitations from the (0.5, 0.5) position using the tetragonal unit cell.

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