The interplay between magnetism and superconductivity (SC) and how one phase is transformed to the other by doping, $p$, continues to be one of the most prominent questions in the physics of high-temperature superconductivity (HTSC). For the $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$ (YBCO$6+x$) family of superconductors, no studies have been made of whether the antiferromagnetic (AF) Néel phase is contiguous to the superconducting phase or whether a different phase such as the spin-glass phase of LaSrCuO separates them. A boson superconducting phase or whether a different phase such as the antiferromagnetic (AF) Néel phase is contiguous to the superconducting order. In addition to the central mode, a damped excitation (central mode), but not with long-range antiferromagnetic order. Nevertheless, they remain in the orthorhombic phase, so that short oxygen chains are still available as a sink for holes. Neutron scattering measurements were performed at the C5 triple-axis spectrometer. A pyrolytic graphite (PG) vertically-focusing monochromator and a large flat analyzer were used at a fixed final neutron energy of $E_n = 3.52$ THz. Two PG filters were used in the scattered beam to suppress higher order contamination. The horizontal collimations were set to [none, 0.48°, 0.55°, 1.2°].

The neutron scattering from YBCO6.31 shows no evidence for 3D Bragg resolution limited AF peaks. Instead we find that AF correlations behave similarly to those in more highly doped samples but now with even larger correlation lengths (see Figure 1). Along the $c$-direction, which couples the planes the correlations are clearly of finite range (~ 70 Å) and thus exclude the existence of 3D Bragg peaks. Within the $ab$-plane the correlations are too long to be determined accurately with thermal neutrons. The absence of Bragg order is also confirmed by the temperature dependence of central mode, which shows only a smooth increase with decreasing temperature with no anomaly that might signal a transition below a sharp Néel temperature. The lack of 3D Bragg AF peaks as well as lack of evidence for a transition suggests that, similarly to very underdoped but superconducting samples, the spins are organized in a spin-glass phase. This is further supported by the fact that at very low temperatures a decrease in the peak intensity of the central mode is observed upon cooling below $T \sim 20$ K.

Compared to YBCO6.33 with $T_c = 8.5$ K, we find that the AF correlations are longer in YBCO6.31 but still remain finite. In addition in YBCO6.31, correlations start to grow at temperatures larger than for YBCO6.33. This study shows that there is an intermediate phase between the long range AF ordered and superconducting phases. The observed behaviour is consistent with a spin-glass phase. The absence of long range AF spin order does not require the presence of Goldstone spin-waves and renders the boson interpretation of thermal conductivity unlikely. Samples with even lower doping than YBCO6.31 will be required to access the long range AF ordered region of the phase diagram.
Fig. 1 The background subtracted elastic data around the AF position (0.5 0.5 2) along [H H 2] and [0.5 0.5 L] directions in non-superconducting YBCO6.31 are compared to those in superconducting YBCO6.33 (Tc = 8.5 K). The fits to a Lorentzian form 1/(\kappa^2 + \kappa^2/4) are shown. Although larger, correlations remain finite in YBCO6.31.

References