Two Pseudogaps in the Cuprates

From measurements of the thermal expansion anomaly in underdoped $YBa_2Cu_3O_{7-\delta}$ (YBCO), Meingast *et al.* [1] claim to have shown that the pseudogap effect is associated with superconducting fluctuations alone. However, the fluctuations they observe do not persist all the way up to the pseudogap onset T^*. In fact, Fig. 1 shows that these fluctuations, as well as all other direct evidence for superconducting fluctuations in *all* the cuprates—YBCO, $Bi_2Sr_2Ca_xCu_{x+1}O_{8+\delta}$ (Bi22x, $x+1$, $x = 0, 1$), and $La_{2-x}Sr_xCuO_4$ (LSCO)—terminate at a well-defined temperature $T'(x)$ which is considerably lower than T^*, with a different doping dependence (clearer saturation or turnover at low x). Here T^* is determined from a variety of nonsuperconducting measurements: transport and heat capacity (dashed line) [2,3], photoemission leading edge (dotted line) [4], and tunneling "peak" feature (filled circles) [5], assuming $2\Delta/k_BT^* \simeq 6$ [approximately consistent with Ido *et al.* [6], who found a ratio 4.3]. Onset of superconducting fluctuations at T' is found from magnetic measurements (Cu NMR $1/T_{2G}$ reduction) [7], onset of Kosterlitz-Thouless fluctuations [8], interlayer Josephson tunneling [9] and magnetoresistance [10], and vortex fluctuations [11]. The fluctuations found by Meingast *et al.* clearly fall into this group, extending to only about $2/3 of$T* at the lowest doping. Note that T^* and T' correspond well to the large and small tunneling gaps found by Krasnov [12].

If the weak pseudogap is caused by fluctuating superconductivity, then the opening of the leading edge gap would suggest that the order parameter *amplitude* is large at T^*, and the absence of any evidence for *phase* fluctuations until the much lower temperature T' is, to say the least, very puzzling. Meingast *et al.* must postulate that the fluctuations persist, but their measurements lose sensitivity well before T^*. Recent data on Bi-2201 [10] makes this postulate highly unlikely. Here T_c is only 3 K in the pure compound, rising to 29.7 K in Li substituted material. But *for all these compositions, T' is the same as that found in bilayer cuprates.* Such a coincidence strongly suggests that T' represents a real crossover line, unanticipated in the fluctuation model of the pseudogap.

Thus, the combined evidence of Fig. 1 provides strong evidence of *new physics* in the range between T' and T^*, unrelated to superconducting fluctuations. Several early models [13–15] proposed the existence of *two* pseudogaps in the cuprates, with only the lower of the two, the "strong" pseudogap T', being associated with superconducting fluctuations. In particular, the two gaps are readily explained by phase separation models (including stripes) of the cuprates. For instance, Batlogg and Emery [14] suggested that the weak pseudogap corresponds to the onset of electronic inhomogeneity (stripe fluctuations), and the strong pseudogap to the onset of superconductivity on individual stripes, while the macroscopic superconducting transition T_c is a signature of the establishment of phase coherence between stripes.

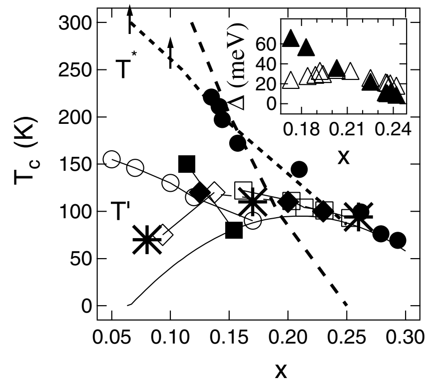

FIG. 1. Doping dependence of T_c (solid line) and superconducting fluctuations in Bi2212 (open [8] and solid diamonds [7]), YBCO (solid [9] and open squares [1]), Bi2201 (stars) [10], and LSCO (open circles) [11]. Dotted line: leading-edge pseudogap from photoemission [4] (arrows indicate that temperatures are only lower limits); thick dashed line: weak pseudogap temperature T^* in YBCO [3]; solid circles: $\Delta/3$, where Δ is the peak position measured in tunneling [5]. Inset: triangles: two gaps found in interlayer tunneling [12].

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