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Quantum critical behavior in the superfluid density of strongly underdoped ultrathin copper oxide films[1]

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The relationship between transition temperatures T_C and superfluid densities $n_S(0)$ of cuprate superconductors has been a central issue in cuprate superconductivity from the beginning. When mobile holes are removed from optimally doped CuO_2 planes, T_C and $n_S(0)$ decrease in a surprisingly correlated fashion. Recent measurements of the superfluid density of strongly underdoped $YBa_2Cu_3O_{7-\delta}$ films and crystals have found a square-root scaling, $T_C \propto n_S(0)^\alpha$ where $\alpha \approx 1/2$, which supplants the approximately linear proportionality that had been deduced long ago from less underdoped samples by Uemura et al. and had been ascribed to the quasi-2D structure of cuprates. This situation leads back to a basic question – what is the behavior of the fundamental structural unit, namely, a single CuO_2 layer or bilayer, which is truly two-dimensional by construction? To address this question, we studied 2D samples near the critical doping level where superconductivity disappears. We measured $n_S(T)$ in films of $Y_{1-x}Ca_xBa_2Cu_3O_{7-\delta}$ as thin as two CuO_2 bilayers. T_C's were as low as 3 K. We observed the 2D Kosterlitz–Thouless–Berezinski drop in n_S at T_C, and we recovered the linear scaling $T_C \propto n_S(0)$ expected in 2D due to fluctuations in the phase of the superconducting order parameter. Taken together, results on 3D and 2D samples suggest that the disappearance of superconductivity with underdoping is ultimately due to quantum fluctuations near a quantum critical point.

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