Universality of the "1/8th" anomaly in Cuprates

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"Evaluation of CuO_2 plane hole doping in $YBa_2Cu_3O_{6+x}$"

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Recommended with a commentary by S.A.Kivelson, Stanford University

The cuprates may be the most studied materials, ever, and they exhibit an extremely large variety of phenomena that are interesting in their own right. Of particular interest, however, is the phenomenon of high temperature superconductivity (HTC). To glean clues from experiment concerning the physics of the high superconducting transition temperature, T_c, one would like to focus primarily on phenomena which: 1) occur in all the different families of cuprates in the range of dopings in which they are superconducting ("universal"' phenomena), 2) occur on temperature and energy scales relevant to superconductivity (as opposed to subtle, low temperature "epiphenomena"), 3) correlate in some way with T_c. One of the most striking universal observations is an exceptionally strong, non-monotonic dependence of T_c on the doping density, x (defined relative to the parent antiferromagnetic insulating state which occurs at x=0): T_c rises from 0 beyond a critical doping density, $x_{c1} \approx 5\%$ reaches a maximum at $x = x_{opt} \approx 15\%$, and then drops to zero at $x_{c2} \approx 25\%$. This extreme sensitivity to alloying is one of the clearest differences between the cuprates and more conventional superconductors.

There is a further wrinkle, known as the "1/8 anomaly," concerning the x dependence of T_c, which has been well documented in the 214 families of hole doped cuprates: There is an anomalous suppression of $T_c(x)$ in the neighborhood of $x = 1/8$ which in some cases (such as $La_{2-x}Ba_xCuO_4$) is so pronounced that T_c goes essentially to zero at $x = 1/8$, but achieves reasonably high values both for $x_{c1} < x < 1/8$ and for $1/8 < x < x_{c2}$. Neutron and X-ray scattering studies have shown that the suppression of T_c in these materials is associated with the occurrence of relatively strong charge order "stripes." However, it has been unclear whether the 1/8 anomaly is special to this family of materials which anyway has relatively low transition temperatures, $T_c \leq 42$K. Suggestive evidence of a 1/8 anomaly in other cuprate families has been presented previously, for instance from μSR measurements on Zn doped YBCO and BSCCO[1]. However, in these other families of cuprates it is difficult to directly determine the doping concentration, x, from the chemical stoichiometry, so it is hard to establish what features correspond to anomalies precisely at $x = 1/8$.

In the present paper, Liang, Bonn, and Hardy have performed a structural measurement of a quantity (a c-axis lattice parameter) which plausibly provides a direct measurement of x in their high quality crystals of $Y_1Ba_2C_3O_{7-\delta}$. They are then able to establish a quantitative relation between x and δ, and thus $T_c(x)$. What they find is that there is a dramatic ($\Delta T_c \sim 17$K) suppression of T_c in a neighborhood ($x = .125 \pm 0.025$) of $x = 1/8$. This new finding strongly supports the notion that the 1/8 anomaly is a universal feature of the HTC story, and that it is not a low temperature curiosity but something that has a substantial effect on T_c, even when T_c is 70K or larger.

This leaves open the question of the physical origin of the "universality," since stripes, at least of the static variety, have not been found in YBCO. Comparably careful studies of the doped hole dependence of T_c in other families of cuprates will be needed, as well, to determine just how universal is universal.

[1] I. Watanabe ıet al, "Muon-spin relaxation study on the Cu-spin state of $Bi_2Sr_2Ca_{1-x}Y_x(Cu_{1-y}Zn_y)_2O_{8+\delta}$ around the hole concentration of 1/8 per Cu," Phys. Rev. B **62**, 14524 (2000) and M.Akoshima *et al*, "Anomalous muon-spin relaxation in Zn-substituted $YBa_2Cu_{3-2y}Zn_{2y}O_{y-\delta}$ around the hole concentration of 1/8 per Cu," Phys. Rev. B **62**, 6761 (2000).