Comment on "Observation of the Conductivity Coherence Peak in Superconducting $Bi_2Sr_2CaCu_2O_8$ Single Crystals"

One of the striking features of high-T_c superconductors that was observed early on is that the so-called Hebel-Slichter coherence peak in the nuclear-spin relaxation rate is absent [1]. Such a peak occurs in BCS superconductors in the conductivity $\sigma_1(\omega)$ [at frequencies much less than the gap $\Delta(0)$] as well as in the NMR. Although measurements of $\sigma_1(\omega)$ at frequencies $\omega \lesssim \Delta(0)$ indicated that the conductivity coherence peak might also be absent in the high-T_c materials [2], measurements by Holczer *et al.* [3] at a frequency of 60 GHz [$\ll \Delta(0)$] on $Bi_2Sr_2CaCu_2O_8$ single crystals show a well-pronounced peak which they attribute to a type-2 coherence effect. However, the observed peak is much narrower than those of BCS superconductors, and occurs very close to T_c. Holczer *et al.* mention strong-coupling effects as a possible explanation for this narrowness. We have verified numerically that this is indeed possible, with $2\Delta/kT = 8-9$, provided the gap as a function of temperature remains practically constant up to temperatures very close to T_c and then drops extremely rapidly. Such an explanation would, however, also lead to a coherence peak for the NMR.

The purpose of this Comment is to point out that the peak in the data of Ref. [3] could well be entirely due to fluctuations. Two observations concerning the data of Ref. [4] suggest the importance of fluctuation effects. First of all, the enhancement of $\sigma_1(\omega)$ is already visible well above T_c, up to 100 K. As is well known, the almost two-dimensional nature of Bi-Sr-Ca-O (BSCO) makes fluctuation effects in these materials much stronger than in Y-Ba-Cu-O. Second, in the same frequency range experiments have been performed on Pb films [5] with a layer conductance comparable to the conductance of a single Cu-O layer in BSCO. In these, fluctuation effects are only a (5–10)% effect, but with a T_c that is roughly 13 times larger, one expects effects of order unity in BSCO.

More precisely, for films of thickness d, the Aslamasov-Larkin-Schmidt [6] result for the fluctuation conductivity at T_c and at a frequency ω is $\sigma'(\omega) = (e^2/\hbar d)kT_c/\hbar\omega$. This results, with $f = \omega/2\pi = 60$ GHz, in a contribution to the conductance per square of one Cu-O layer, $\sigma'(\omega)d$, of $0.75 \times 10^{-2}\ \Omega^{-1}$. Taking a normal-state resistance per square of a Cu-O plane of 130 Ω around T_c, this gives an enhancement of σ_1/σ_{1N} at T_c of 1.9, the height of the peak observed by Holczer *et al.* Martin *et al.* [4] quote a resistance per square of 300 Ω, which predicts a fluctuation enhancement of about 4, i.e., larger than observed.

The Azlamazov-Larkin-Schmidt result is valid above T_c. Fluctuation effects below T_c have been investigated by Schmidt [6]. At T_c the fluctuation conductivity as calculated below T_c joins the result obtained above T_c, leading to a maximum at T_c. In Fig. 1 we show the result of a numerical calculation in which σ_1 is the sum of the fluctuation conductivity given by Schmidt and the conductivity given by a type-1 (or "two-fluid") behavior *without* a coherence peak, as in the NMR data. In this calculation, we take $T_c = 88$ K, which is slightly lower than the 91 K reported by Holczer *et al.*, and the gap has a BCS-like temperature dependence with $2\Delta(0)/kT_c = 6$. The dots in the figure are some of the data points of Holczer *et al.* Although the peak which we obtain in this way is narrower than the one observed experimentally above T_c, this illustrates that there may not be a coherence peak. Fluctuations affect the NMR in the opposite way, so that there cannot be a fluctuation-induced peak in the NMR data.

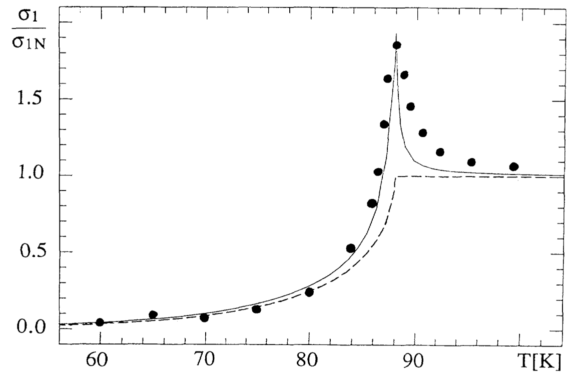

FIG. 1. σ_1/σ_{1N} with σ_1 (solid line) the sum of a type-1 behavior (dashed line) and the fluctuation conductivity.

Measurements at different frequencies may resolve whether part of the peak or even the whole peak is due to fluctuations since the height of the fluctuation peak is inversely proportional to the frequency, whereas the height of a coherence peak has a weaker frequency dependence.

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